P a r t 7

ENERGY SAVING

7.2. Application of expander-generating apparatuses in process of using the technological pressure drop at natural gas conveying

7.2.1. Physical bases and estimation of EGA operational efficiency

Agababov V.S., Koryagin A.V.; MPEI(TU)

As it is known, the underground layer of natural gas is of a high pressure. A high pressure of the layer is partially used for transportation of natural gas through the main pipelines at considerable distances to the consumption site. In case of gas combustion in the industry or in a life, its pressure should be considerably lowered in comparison with the pressure in the main pipelines. This decrease usually occurs due to throttling.

Expander-generating aggregate (EGA) represents a device, in which energy of a flow of the transported natural gas will be transformed, firstly (with pressure and temperature loss), into mechanical energy in the expander, and then into electric energy in the generator. There is also a principal possibility of beneficial use of cold, formed as a result of expansion of the gas flow in the expander, and also heat reception.

Let's consider a system of gas supply of the consumer in which natural gas is used as a fuel (Fig. 7.6).

Natural gas from a layer *1* enters the surface in the "head" of a hole *2*. Gas pressure at the hole output is below 16 MPa, gas temperature is below +35 °C. Having passed cleaning in the mechanical filter *3* and having released from the transported moisture in the dehumidifier *4*, natural gas through the throttling device *5* is supplied to the main pipeline *6*. In the throttling device *5* there is a pressure drop of the gas flow up to the pressure in the main pipeline which in territory of Russia makes either 5,5, or 7,5 MPa, depending on a pipeline type. At transportation on long distances there is a pressure drop of gas because of friction in the pipeline, and also decrease in its temperature (and internal energy) as a result of heat exchange with environment. Gas pressure losses are compensated as required at compressor stations *7*.

A technology of further gas using as a fuel at the existing system of gas consumption requires decrease in its pressure to 0,1 … 0,3 MPa. Gas pressure is usually decreased in two stages: at gas-distribution stations (GDSs) *8* from pressure in the main pipeline to 1,0—1,5 MPa and at gas-distribution plants (GRPs) *9* from 1,0 … 1,5 to 1 … 3 MPa (Fig. 7.6). Pressure of the gas flow at GDSs and GDPs decreases, as a rule, by throttling. After GDPs natural gas is fed to the fuel-utilizing device *10* for combustion (for example, power boiler of the power plant, schematically represented in Fig.7.6.). Use of EGA instead of throttling devices is possible both in the first stage of pressure drop (GDS), and in the second one (GDP).

Conditions of gas flow using after pressure drop stations are usually quite different. So, after GDS, usually located far from gas-consumption equipment, gas is supplied to the GDP, being in immediate proximity from the enterprises — gas consumers. Distance from the GDS to the GDP commonly makes from several units to several tens kilometers. Enthalpy of gas, transported through pipelines on long distances after GDS can change (that usually occurs) at the expense of heat exchange with environment. After the GDP gas is more often used as a fuel in any technological furnaces, power boilers, etc. Enthalpy of the gas flow in this case influences the thermal profitability of gas-consumption equipment operation, as the total energy, released by the gas flow in the boiler furnace or the furnace chamber, is defined not only by its combustion heat, but also by physical heat (enthalpy) of the flow.

Let's consider the process plots, resulted in *h,S*-diagram in Fig. 7.7, which occur at throttling of the gas flow and at pressure drop due to EGA application.

At pressure drop (process 0—1) the gas flow enthalpy doesn't change. At pressure drop of gas by means of EGA the enthalpy of the gas flow decreases at the expense of transformation of a part of the gas flow energy into mechanical work in the expander. Various options of the process arrangement are thus possible:

1. Expansion in the expander without gas heating before it.

The process is represented by a line 0—2 in Fig. 7.7.

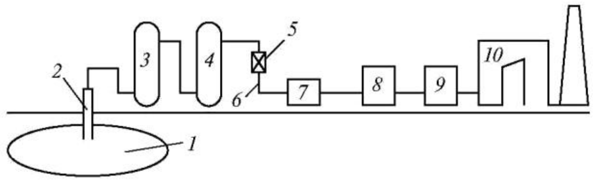

Fig. 7.6. A block-diagram of customers' gas supply:
1 — gas layer; *2* — "a head" of the hole; *3* — mechanical filter; *4* — dehumidifier; *5* — throttling device; *6* — main pipeline; *7* — compressor station; *8* — a gas-distribution stations; *9*— a gas-distribution plant; *10* — gas consumer (boiler)

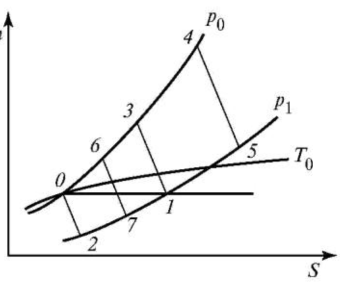

Fig. 7.7. Processes, occurring in the expander, in *h,S*-diagram

Thus, there is also a decrease in the gas temperature. In case EGA is set at the GDS, at further transportation to GDP, as a rule, enthalpy of the gas flow in due course is restored to the initial level at the expense of heat exchange with environment (process 2—1). In case EGA is installed at the GDP and gas, transported at long distances has no time to heat up in the pipeline at the expense of heat exchange with environment without gas heating after the expander, the physical heat of fuel supplied to the furnace, will appear less, than at throttling, by enthalpy difference $\Delta h_{02} = h_0 - h_2$, equivalent to mechanical work of the expander. The heat necessary for increase in the gas flow enthalpy to its initial level in this case (process 2—1), should be suppied either to the furnace of gas-utilizing equipment due to additional fuel combustion, or in the heat exchanger without application of any additional devices for the account of low-potential heat source (heat from environment or heat from secondary power resources). The last possibility is caused by that at parameters of the transported gas, existing in actual practice, gas flow temperature at the expander output in the absence of gas heating before the expander was much less than the ambient temperature.

It should be noted that the existing technological restrictions, concerning the negative gas temperature, make this option to be almost inapplicable for use.

2. Expansion in the expander with gas heating before it.

a) In one of the possible cases the gas is warmed up before the expander due to high potential heat, so (line 0—3 in Fig. 7.7) that the gas flow enthalpy after the expander is equal to the enthalpy of the gas flow after throttling. Thus, all heat supplied to the gas (it is proportional to the enthalpy difference $h_3 – h_0$) will be transformed in the expander into mechanical work. The obtained in the expander mechanical work transforms into electric energy in the generator (except for mechanical and electric losses in the generator).

b) Gas before the expander can be warmed up so (line 0—4 in Fig. 7.7) that its enthalpy (point 5 in Fig. 7.7) at the expander output will be more, than at throttling. In this case only a part of heat supplied to gas proportional to $h_4 – h_0$, will be used for mechanical work generation (this part is proportional to the enthalpy difference $h_4 – h_5$). The second part of heat supplied to the gas flow, is proportional to the enthalpy difference $h_5 – h_0$, at using EGA at GDP it will also be beneficially utilized — used for increase in physical heat of the gas flow, entering the furnace. The increase in physical heat of the gas flow fed to the furnace will lead to fuel consumption decrease in the boiler by value proportional to $h_5 – h_0$. Applying EGA at GDS, the energy proportional to the enthalpy difference $h_5 – h_0$, is lost at the expense of heat exchange with environment at further gas transportation.

c) There are possible, as well, other ways of gas heating in EGA. So, gas can be warmed partially up before the expander, partially — after it (process 0—6 in Fig. 7.7). There are also flow diagrams with gas heating before the expander with the subsequent intermediate heating of gas after its passage through the part of stages of the expander. However, all of them are various combinations of the considered above ways of gas heating.

To estimate an efficiency of EGA application, the effective efficiency, recommended in [1], representing the relation of useful work A_{use} to the supplied energy E_{sup}, can be used:

$$\eta=A_{use}/E_{sup} \qquad (7.1)$$

For example, in the case, when the gas flow enthalpy after the expander at its further transportation, as a result of heat exchange with environment, is the same as it would be at the flow throttling, only electric power, generated in EGA, can be considered as specific useful work. At diagram in a process 0—3—1 for a mass unit of gas it is equal to the difference $h_3 – h_1$, in a process 0—4—5 — the difference $h_4 – h_5$. The specific energy supplied to gas in a process 0—3—1 is equal to the difference $h_3 – h_0$, in a process *0—4—5*— the differences $h_4 – h_0$. Comparison of the effective efficiency for the both considered cases shows that in the process *0—3—1* it will be higher than in the process *0—4—5* as in the second process the energy equal to the enthalpy difference $h_5 – h_1$ and obtained by gas at heating, is irrevocably lost because of dissipation in environment. If energy $h_5 – h_1$ can be partially or is completely used for increase in physical heat of the gas flow, entering the furnace, it is necessary to consider decrease in fuel consumption occurring, thus, in gas consuming equipment.

For the process *0—4—5*, equation (7.1) in the case when it is not necessary to consider EGA influence on operation of energy saving equipment, is the following:

$$\eta_e = \frac{h_4 - h_5}{h_4 - h_0}, \qquad (7.2)$$

and when EGA influence on operation of energy saving equipment should be considered

$$\eta_e = \frac{h_4 - h_5 + (1+\gamma)(h_5 - h_1)}{h_4 - h_0}, \qquad (7.3)$$

where γ is a part of the gas flow energy, lost at transportation from EGA to gas consuming equipment.

It is obvious that for the process *0—3—1* in both cases equation for the effective efficiency looks as follows:

$$\eta_e = \frac{h_3 - h_1}{h_3 - h_0}. \qquad (7.4)$$

Let's pay attention to that the enthalpies h_0 and h_1 (Fig. 7.7) are the same, and the expander effective efficiency (without losses into environment) in this case makes 1. In this context the expander can be considered as the unit similar to turbine, working under counter-pressure.

For the process *0—6—7—1* effective efficiency of the expander can be estimated from the equation

$$\eta_e = \frac{h_6 - h_7}{h_6 - h_0 + h_7 - h_1}. \qquad (7.5)$$

If gas heating is arranged so that for $h_6 – h_0$ heat supply the fuel is combusted, and for $h_7 – h_1$ heat supply the environmental heat, or waste heat is directly used, this case will differ from a case when fuel for heat supply is combusted both at the site *0—6*, and at the site *7—1*, from the point of view of expenses for heat supply. In order to estimate the efficiency of using the waste heat or environmental heat for gas heating it is offered to enter an indicator named as a factor of the used heat value (FUHV) K_{FUHV}, defined as follows

$$K_{FUHV} = 1 - \frac{Q_{lps}}{Q_{sup}} \qquad (7.6)$$

where Q_{sup} — all heat supplied to gas, kJ; Q_{lps} — heat supplied to gas in the low-potential source of heat (LPS) with waste heat or environmental heat, kJ.

At Q_{lps} = 0 the factor K_{FUHV} = 1, at $Q_{lps} = Q_{sup}$ the factor K_{lps} = 0, i.e. with decrease in the factor of the used heat value K_{FUHV}, the expenses for fuel at gas heating arrangement are reducing.

It is obvious, that the same discussions can be made in case when gas isn't heated before the expander.

Thus, if gas after EGA is supplied at once for its combustion, an efficiency of EGA use for electricity generation is necessary for defining, how it will affect technical and economic indicators, in particular, fuel consumption of all installation, as a whole, including gas-utilizing equipment, in comparison with the case when gas pressure drop occurs for the account of the flow throttling.

Estimating the overall EGA performance when it is necessary to consider its influence on operational indicators of the capital equipment, let’s also mention two options of its use:

1) at the enterprise generating electricity;

2) at the enterprise which doesn’t generate electricity.

The first group includes all thermal power plants (Condensing and Combined Heat Power Plants), combusting gas.

The second one covers all other consumers of gas as a fuel, having their own GDPs: heating and industrial boiler-houses, nonferrous-metals and ferrous industries, chemical industry, etc.

Use of EGA at power plants allows either to raise the available capacity and, consequently, electricity generation at TPPs, or, keeping the total generation at TPP constant, to generate a part of electricity with higher efficiency at EGA, than at steam-turbine plants, reducing electricity generation at steam-turbine equipment. The first of the considered options is characteristic for the deficit power system [2, 3], the second — for the surplus ones [4].

In both cases the efficiency of EGA use at TPPs can be estimated by change of the power plant efficiency on electricity generation, or of the specific heat consumption for electricity generation, or of the specific reference fuel consumption for electricity generation after EGA inclusion. Thus, indicators should concern operation of all TPPs, as a whole.

So, if the specific heat consumption for electricity generation at TPP with condensing turbines before EGA inclusion in its thermal flow diagram can be defined from the equation

$$q_{e0} = Q_{KA\,0}/N_{e0}, \qquad (7.7)$$

after EGA inclusion the specific heat consumption for electricity generation is defined as follows

$$q_{э1} = \frac{Q_{KA\,0} + Q_{EGA} + \Delta Q_{KA}}{N_{E1} + N_{EGA}} \qquad (7.8)$$

In equations (7.7) and (7.8) Q_{KA} is a heat, utilized for electricity generation, kJ; N_E — a capacity, generated by the power plant, MW; Q_{EGA} — additional heat, utilized for maintenance of EGA operation, kJ; ΔQ_{KA} — a change of heat amount, connected with change of the gas flow enthalpy at change of gas parameters in comparison with its parameters at throttling, MW; N_{EGA} — the electric capacity, generated by EGA, MW.

The index “0” in equations (7.7) and (7.8) concerns the power plant operating mode without EGA, i.e. at throttling of the gas flow at GDP before its feeding to the boilers, the index “1”— concerns the operating mode with EGA.

The value Q_{EGA} depends on a choice of the way of gas heating (at the expense of heat of the bleed-off steam, use of environmental heat or secondary power resources, etc.), from the power plant operating mode (with maximum electric loading or not, in deficit or surplus power supply system, etc.). The value ΔQ_{KA} depends on the gas enthalpy at the expander output, influencing, as it has been shown above, on change of fuel consumption in the boiler (fuel consumption in the boiler in comparison with its consumption before EGA inclusion, can be both increased — at the gas flow enthalpy, being less, than before EGA inclusion, and reduced — at the flow enthalpy being higher, than before EGA inclusion).

Using EGA at the enterprises, generating no electricity, in conditions when its work influences the operational indicators of the capital equipment, the overall EGA performance can be estimated according to the expression (7.1).

In process of choosing the criteria for estimation of the overall EGA performance, it is also necessary to consider, for what system the problem is being solved, i.e. what objects are included into the considered system and what are the external ones for the system, and also whether the system is connected with external elements by electricity overflows. Let’s explain it by an example. So, at EGA inclusion in the thermal flow diagram of TPP, it is possible to estimate the efficiency of EGA application both for the isolated TPP, and for the power supply system, including this TPP. At economic relations, recently developed between TPP and the power system, and also between power supply systems, both approaches are competent. In the first case at the set schedule of dispatching loading of TPP, EGA can be used for generation of electricity with less specific expenses in comparison with the similar indicators of TPP capital equipment. In the second case there is also a possibility of increase in the generated power at the TPP, where EGA is set, with decrease in electricity generation by one of TPPs of the power supply system with the worst technical and economic indicators of the capital equipment operation. Besides, there is also possible an alternative of power raise of the whole power supply system at the expense of EGA use if the generated additional electricity can be consumed within the limits of the power supply system (at EGA operation in the deficit power supply system) or transferred to the other, the deficit power supply system, at EGA operation in the surplus system.