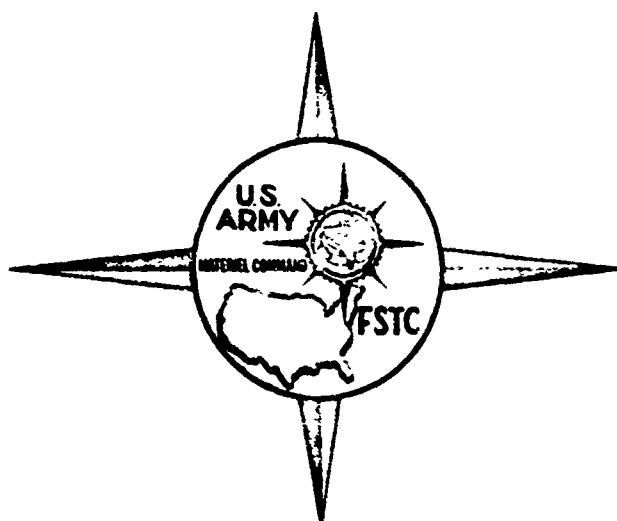


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PATHS OF DEVELOPMENT OF STATIONARY GAS
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PATHS OF DEVELOPMENT OF STATIONARY GAS
TURBINE ENGINES IN USSR

By G.I. Shuvalov & G.G. Ol'khovskiy

USE OF PETROLEUM FUEL AND DISSOLVED ADDITIVES FOR
LOWERING VANADIUM CORROSION IN GAS TURBINE ENGINES

By R.A. Lipshteyn et al

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Abstract:

The first article surveys the results of experimental development of Soviet gas turbine engines and ways of using them in power engineering. Detailed tables are given showing characteristics of various engines. The second article considers the question of choice of additives to sulfurous petroleum fuel permitting the avoidance of appreciable vanadium corrosion during the operation of the gas turbine engines.

PATHS OF DEVELOPMENT OF STATIONARY GAS TURBINE ENGINES IN USSR

G. I. Shuvalov & G. G. Ol'khovskiy

The industrial application of gas turbine engines (GTE) began relatively recently (15 to 20 years ago). In spite of this, the number of engines being produced by the leading foreign firms of General Electric, Westinghouse in the U.S., and Braun-Boveri in Switzerland is counted in the hundreds while their total power runs to millions of kilowatts. Several dozens of them have already been operating for 60-70,000 hours. Along with the engines of relatively low power (5 - 10 mv), which are widely used not only for the production of electric power but also for the mechanical drive on trunk oil and gas pipelines, in transport and industry, there have been manufactured abroad many powerful GTE for large-scale power engineering. The Swedish firm DeLaval-Jungström has produced and passed through an operating test the assemblies with a power of 40-45 mv; a number of firms are mass-producing the power GTE with a power of 15-30 mv, gas turbine electro-stations with power up to 100 mv have been built, and heating-and power stations with heat output up to 100 large cal/hr have been developed. From year to year, the individual powers of the GTE are continually rising, while their economic and operational characteristics are being improved.

At present the total established power of the power GTE in all countries in the world amounts to about 5 million kv (kilowatts), including installations with individual power of more than 15 mv, i.e. about 2 million kv. The heat characteristics of the largest GTE are shown in Table 1. The main indexes of the gas turbine electrostations are given in Table 2.

In the USSR, the first test-industrial models of stationary GTE were produced in 1955. All of them (Table 3) had a number of features typical for the initial stage of a domestic stationary gas turbine construction; moderate level of initial gas temperatures, absence of effective cooling of hot parts of the turbines and the thereby caused wide application of austenite steels, low forcing of elements of equipment, and multistage design of turbo-machines, free layouts with numerous hot connecting pipelines of large cross sections.

A result of the noted features in the design of the first GTE was their

High specific weights and large dimensions, low mobility, unsatisfactory operation of individual units and parts of the turbines, subjected during operation to abrupt temperature (t°) changes. As a rule, the efficiency values actually being attained for these engines were appreciably lower than those planned. The causes for the divergence were different for the various GTE: inadequate effectiveness of regeneration (GT-600-1.5 and GT-12-3); lower efficiency of individual turbomachines, especially of compressors (PG-50000 and GT-700-4); air leakages from the high pressure ducts; high hydraulic resistances and finally, excessive reserves in the calculations (GT-600-1.5). In the latter case, the engine's efficiency is lowered in connection with the fact that the nominal power of an electric generator is attained at gas t° in front of the turbine that is lower than that planned.

At the same time, even in these initial engines, we developed models of gas turbine equipment, not inferior in technical indexes to the foreign ones: axial compressors with an output up to $60 \text{ m}^3/\text{sec}$, the adiabatic efficiency of which reached 88-90%; turbines with efficiency up to 89%; reliably operating combustion chambers with efficiency of 98-99% at losses of full pressure of about 1%. In all the engines, there was attained a satisfactory agreement of characteristics of individual turbomachines and devices.

The experience in mastering the first Soviet GTE was critically developed by the plants together with the leading scientific-research and training institutes. The production of gas turbines was organized at practically all the turbine-building plants in the Soviet Union. It should be stressed that the parallel work of the same plants with steam and gas turbines, the creation of which requires a higher level of designing and technology, exerted and will exert from now on a creative influence on the practice of steam turbine construction. The turbine builders have learned how to handle austenite steels, have come to use more widely the welding techniques and now technological processing methods, have expanded their experimental base, etc. In the time since 1960, as a result, a number of leading models of GTE have been made of a completely different form and class. Among them are:

The GT-700-5 NZL, which is now being produced in a large series for main gas pipelines. The three first models of this type of GTU were developed under a load of more than 10,000 hours each and were tested on stand at the factory and at the Novgorod Compressor Station [Refs. 1, 2].

The GTN-9 LMZ, the pilot model of which was adopted in January 1964 after thousand-hour tests under load at the factory stand of the State Receiving Commission.

The GT-25-700 LMZ, the adjustment of which, started in autumn of 1963, is being presently carried on at the TET -2 of Kiev-energo. During fall-winter of 1963-64, this engine was developed (run) with a load of 15-20 mv for more than 2,000 hours without breakdowns or significant malfunctions.

The GTU-50-800 KTGZ, which is being set up at the TET -3 of the Khar'kov-energo, and a number of others.

The technical specifications of these machines are adduced in Table 4 [Refs. 3 - 5]. As a rule, all these new machines are made to run faster.

In the layouts of the gas turbine engines, one often encounters a close arrangement of the turbomachines and devices with bearings, in nature inaccessible without dismantling the cylinders or even located inside the hot pipelines. A number of turbines on the expansion stage 3-4.5 have only 2-3 stages, located on the console rotors. The GTE, without generators, with a power of 6 and 4 mv were manufactured by the Ural turbomotor and Kaluga turbine works in a unitized design.

Almost all the turbines have an intensive cooling of the rotors and parts of the turbines' stator, which permits one to use for their manufacture steels of the perlite and ferrite class at initial gas temperatures of 700-800°C. The adjustment and mastery of these GTE demonstrated that their design principles validated themselves. The mobility and reliability of the engines under operation rose markedly; they became more sophisticated, light in weight and economical. However, the designs of the cooling turbines can by no means be regarded as perfected. In the transition from a cold to a hot state, there occur changes in the clearances in the flow-through part that are difficult to control. Air leaks develop from the cooling systems within the turbines; the air losses to cooling are high, as a result of which the parts of the rotor and stator are supercooled and in them there develop surplus temperature stresses. All these shortcomings lower the reliability and efficiency of the turbines, wherein these efficiencies proved even lower than in the earlier produced uncooled designs: for the 2-3 stage turbines, they were at a level of 80-84%; for turbines with a large number of stages, they were at 85-87%.

It is necessary to combine skillfully the cooling with the internal insulation of the elements of the turbine's frame and with the other known design methods for the stabilization of the clearances in the flow-through part and for the avoidance of residual stresses in the parts.

One should also keep in mind that in the manufactured GTE, we have not succeeded in equalizing the field of temperatures of the working gases at the outlet from the combustion chambers to such a degree to select the material for gas admission into the turbine and for its first nozzle device, orienting oneself on the average (calculated) temperature of the working gases. Therefore the designs and the materials for the indicated elements of the turbines should permit prolonged operation at local temperatures of gas, exceeding the average by 30-50°C, depending on the design of the combustion chambers, their layout, and the fuel being used.

The rise in the individual powers of the GTE to 25-50 mv became possible after the development of compressors with an output of 170-175 m³/sec. Such compressors on the compression stage 2.5-3 were designed by the LMZ and the KTGZ on the basis of the K-50-1 TKTI profile. Natural tests showed that the adiabatic efficiencies of these machines under conditions close to the designed ones amounted to 85-86%. These and other new types of axial compressors for the stationary GTE, developed in recent years by domestic factories have fair economic specifications (according to tests at $G = 30-50$ kg/sec and $\epsilon = 3.5 - 5$, $\eta_{lk}^{ad} = 86-87\%$). However, not in any one of them was there attained an efficiency of 89-90%, that was obtained many years ago by the LMZ for a GT-12-3 in compressors with profiles K-100-4 or LKZ in the well-known compres-

sor based on the GTU-42. The basic cause for this is the circumstance that for practical purposes, the plants do not engage in the finishing of already produced natural compressors in the sense of establishing the optimal pitches of the blades in the individual stages, the optimal axial and radial clearances, the improvement of the connecting pipes etc. At the same time, the experience of the NZL, obtained on the GTU-700-12, indicates that with the aid of relatively simple methods in these directions, the efficiency of the compressors can be significantly improved even at a high (88-89%) original level. In addition to the further increase in the efficiency, of the main design problem for these machines is the assurance of the necessary rigidity and stability of their housings for the retention of constant design radial clearances in the flow-through part. Validated and useful for reducing the radial clearances is the method of applying a special cement to the inner surface of the housing.

The difficulties involved in operating the compressors is linked with foulings of the flow-through part, which can have a varying nature in dependence on the positioning of the compressor in the GTE layout and cause for 500-1000 hours a drop in output of pressure and efficiency of compressors by 3 - 5%.

The rise in the operating speed of the turbomachines, the increase in the load of individual stages, the development of light and stressed designs place more rigid requirements on the sophistication, precision and production quality of the equipment. Unfortunately, our turbine-producing plants do not always meet these stipulations. It is quite clear that the further progress not only of gas turbine construction, but also of steam turbine construction will be impossible without a marked improvement in the quality control by way of bettering the technology and raising the technological discipline.

The majority of the stationary GTE of this period were planned with reprocessing (of the fuel), while the largest of them were planned to have intermediate cooling of air under compression. The further design development resulted in a regenerator based on profile punched-out sheets, than had been made for a long time by the NZL. For the GT-700-5, this regenerator was made as a counterflow model. At $F = 1400 \text{ m}^2$, the recovery stage comprised 70-72% [Ref. 2].

For the GTN-9 and GTU-50-800 engines, the LMZ and KTGZ planned and produced the counterflow regenerators, in which the heating surface was formed by pipes with longitudinal ribbing along the gas side. In the GTU-50-800 regenerator, we attained a compactness factor of $235 \text{ m}^2/\text{m}^3$ and a specific weight of 4.4 t/mv [Ref. 6].

As tests have shown on an analogously designed regenerator GTN-9, it has specifications close to the designed ones. In the course of over 1000 hours test operation with repeated starts and stops of the gas turbine engine, these characteristics hardly varied.

Table 1

No. in sequence	Manufacturer	Year of mfr.	Cycle ¹	Type	Power, mv	Temp. before turbine, °C	Deg. of compression	Output of working body, kg/sec	Design efficiency, %	Fuel	A	B	C
1	De-Laval Jungström	1959	0	3 shafts	40-42	700	13	262	27	Mazut	6-12	-	2
2	Fiat	1961	O.P	2	"	36-?	16	178	27	PG, ZH	40	240	1
3	Westinghouse	1960	Simp.	1	"	22-27*	6	194	23	PG, ZH	30-45	120	2
4	Brown-Boveri	1955	O, P	2	"	20-30	16	158	25	PG, Mazut	18	-	30
5	The same	1958	R	1	"	16-17	5.7	158	28	DG, LZH	40	800	8
6	General Electric	1958	Simp.	1	"	16.5-21.3	6	123	22	PG, Maz.	15-30	-	10
7	The same	1958	R	1	"	18	6	--	28.6	"	"	-	2
8	Siemens-Schuckert	1960	R	1	"	22	6.5	184	29	PG, LZH	--	400*	1
9	AEG	Plan	O, P	2	"	30	17	145	26	GG	--	332	-
10	LMZ GT-100	1965	O, P	2	"	100	26.3	430	28-30	PG, ZH	--	650	-

¹ O = cooling; P = repeated heating; R = generator.

² GG = generator gas with $Q_n^P = 6,336$ large cal/kg (about 26,500 kilojoules/kg); PG = natural gas; ZH = liquid; L = light; and DG = blast-furnace gas.

* = summer and winter power.

** With electrical generator, but without heat exchangers.

A = Starting time, minutes;

B = Weight, tons; and

C = number of machines

Table 2

Electrostations	Total power, mv	Number, ex & type of GTE ¹	Purpose	Year made	No. of service personnel, men per shift	Specific ic area, m ² /mv	Specific ic vol., m ³ /mv	Cost, of estab ² , power, \$/kv	Fuel
Port-Mann (Canada)	100	4X25(4)	Peak	1958	Auth.	25	450	120	PG, oil
Georgia (Canada)	76	2X19.8(6) 2X18(7)	Base	1958	11.	27	400	130	Mazut
Westervik (Sweden)	40	1X40(1)	Peak	1959	1	26	510	85	Mazut
Edmonton (Canada)	50	2X25(4)	Peak	1959	Auth.	**	**	84	PG
Livorno (Italy)	50	2X25(4)	Peak	1955	*	**	**	87	Mazut
Stedlitz (Berlin)	50	2X25(4)	Peak	1960	2-3	20	440	100	"
Bremen (FRG)	50	2X25(4)	Peak&?	1959	*	31	---	126	"
Korneuburg (Austria)	75	2X25(4) PTU	Gassed	1959	*	24	---	---	PG, ZH
Munich (FRG)	44	2X22(8)	(?)	1961	---	44	880	---	PG
Betznaun (Switzerland)	40	27+13	Peak	1949	4	30	---	---	Mazut
Caracas (Venezuela)	44	22(4)+21.8(6)	Peak	1958	Auth.	---	---	---	PG, ZH
Kivasso (Italy)	32	36.6(2)	---	1961	---	15	580	---	" "
Barbados	25	25(3)	Peak	1961	Auth.	39	---	---	" "

¹ Numbers in parentheses correspond to the number of line in Table 1.

* Each gas turbine engine (GTE) is serviced by one man per shift.

** Analogous to the data for the Stedlitz station.

Table 3

Nomenclature	GT-600-1.5	GT-700-4	PG-50000	GT-12-3	
Year produced	1955	1957	1956	1955	
Barometric pressure, B, bar	0.981	0.981	0.081	0.981	
T° before turbine, $t_{do\ t}$, °C	546-600	700	600	650/650	
T° before compressor, °C	+5	+15	+5	+17	
$t_{do\ k}$					
Power, N, kv	1500-1880	3810*	1800	12 740	
Rated power N_r , kv	1500	4000	2210	12 000	
Efficiency, η , %	16.9-18.8	16.0*	14.8	24.5	
Rated efficiency, η_r , %	18.6	25.0	10.0	27.0	
Max. abs. pressure, p_{max} , bar	— —	4.78	3.54	13.9	
Ratio of t° , $T_{do\ t}/T_{do\ k}$	2.965 3.14	3.38	3.14	—	
Reduced ratio $T_{do\ t}/T_{do\ k}$					
$X \eta_k \cdot \eta_t$	2.185 2.315	2.355	2.10	—	
Useful work factor, $N/\Sigma N_t$	0.273 0.32	—	0.249	0.294	
Specific work N/G_v , kilojoules/kg	50.8 63.4	85.6	53.5	145.5	
Relative pressure losses, ϵ_k/ϵ_t , %	13.0	5.8	12.0	9.0	
Degree of recovery, σ , %	61.3	—	54.8	66.7	
Effective degree of recovery σ^* , %	24.9	—	35.4	58.1	
Fuel savings, δQ , %	31.0	—	32.5	23.5	
Effective fuel savings, δQ^* , %	13.4	—	48.3	20.4	
Turbines			TND	TND	
Degree of expansion, ϵ_t	3.275	4.36	3.21	3.06	4.43
Available heat drop Δi_s , kilojoules/kg	250	326.5	258.7	258.5	3.44
Ratio, $(u/c_o)_{sr}$	0.616	0.57	0.52?	0.621	0.500
Efficiency of turbine η , %	85.7	84.8	85.5	89.2	86.0
Compressors			VKND	VKSD	VKVD
Number of stages, z	16	22	8*	9	12
Volume output v , m³/sec	24.4	37.0	35.6**	55.5	25.0
Degree of pressure rise, ϵ_k	3.67	4.71	2.85**	2.39	2.08
Degree of reactivity, θ	0.5	1.0	1.0	1.0	1.0
Peripheral velocity, v_1 , m/sec	230	—	228	169	138
Mean pressure factor, ψ_{av}	0.33	0.63	0.59	0.67	0.67
				0.67	0.695

(table cont'd on next page)

Table 3 (cont'd)

Nomenclature	GT-600-1.5	GT-700-4	PG-50000	GT-12-3
Efficiency of compressor, $\eta_k, \%$	87	82.5	78	85
Combustion chambers				
Fuel	M2	Natural gas	DL	DL
Surplus air factor, α	8.6	5.8	8.1	5.1
Heat stresses of furnace space: $Q/pv, \text{gcal}/\text{m}^3 \cdot \text{hr} \cdot \text{at}$	2.64	1.61	2.23	1.00
$\text{kg} \cdot \text{m}^3 \cdot \text{bar}$	3.07	1.87	2.53	1.16
Pressures losses $\Delta p/p, \%$	1.17	2.10	1.49	1.12
Heat efficiency, $\eta'_{ks}, \%$	98.5	99	99	97
Aerodynamic efficiency, $\eta''_{ks}, \%$	95.4	91.9	94.1	95.5
Total efficiency, $\eta_{ks}, \%$	94.0	91.0	93.1	92.5
Regenerators				
Mean t° pressure, $\Delta t_{av}, ^\circ\text{C}$	98	—	102	82
Heat transfer factor, $k,$ $\text{watts}/\text{m}^2 \cdot ^\circ\text{C},$	33.7	—	19.8	26.7
large $\text{cal}/\text{m}^2 \cdot \text{hrs} \cdot ^\circ\text{C}$	29.0	—	17.0	22.8
Pressure losses $\Delta p/p, \%$	9.55	—	3.91	3.24

* Without recovery

** CHID.

The combustion chambers of the GTE under consideration, very diverse in designs and operating parameters are intended for the ignition of one form of fuel, namely natural gas. The efficiency of these combustion chambers equals 98-99% at pressure losses of about 1 - 1.5% (with the exception of the KTGZ chambers, where $\Delta p/p = 2.5 - 3\%$). However, as before, these indexes are obtained at the cost of increasing the dimensions of the combustion chambers. Even in the most improved designs, the differences between the maximal and average t° of the gas in front of the turbine amount to 40-60°, which constitutes their basic disadvantage.

The experimental studies conducted by the plants and the scientific-research organizations (TKTI, VTI, KPI, etc.) furnish a basis for hoping that combustion in analogous combustion chambers of liquid fuel or the combined combustion of liquid fuel and natural gas does not cause any major difficulties.

Table 4

Nomenclature	LMZ	KTGZ	NZL	LMZ
	GT-25-700	GT-50-800	GTN-5-700	GTN-9-750
Power, kv	25,000	50,000	4,400	89,000
Fuel	G	G	G	G
%Total extent of pressure rise	9.4	18.9	3.9	4.6
Outer air t°, °C	17	20	15	17
T° before turbine, °C	700	800/770	700	750
Degree of recovery	0.8	0.7	0.75	0.65
Engine ¹ efficiency, %	28.0	33.5	25.0	26.0
Air consumption, kg/sec	187	200	45.3	78.5
Consumption of water coolant, m ³ /hr	2,000	4,000	—	0
Specific weight ² of engine, kg/kv	24.5	13.1	22	—
Dimensions of engine room, m	18X36X17	21X27X20	—	—
Specific area, m ² /kv	0.026	0.010	—	—
Specific volume, m ³ /kv	0.44	0.227	—	—

¹ Efficiency at generator terminals for power installation and at supercharger shaft for compressor device.

² Within the delivery limits of the plant.

The basic difficulties originating during the changeover to heavy brands of liquid fuel are not associated with the operation of the combustion chambers or of the fuel systems, but with the deposits on the turbine blades and with vanadium corrosion of the blades' metal. Tests conducted in the VTI on the GT-600-1.5 gas turbine installation on the combustion of brands M40 and M60 fuel oil (mazut) demonstrated that even at $t = 550-600^{\circ}\text{C}$, when the main components of the fuel ash are in solid state, the power of the GTE diminishes from the deposits of the ash components on the turbine blades by 2-3% in a day. The use of inorganic additives to the fuel lowered this figure to 1.0-1.5% per day. In operation with fuel oils with an additive of kaolin to the fuel, in the root part of the guide blades of the turbine's last stages, there occurred an erosion which proved to be avoidable by the installation of removable shield flaps.

The question of the use of heavy liquid fuels is at present quite

acute: even for the "gas" electrostations, it is mandatory to have at hand a reserve, liquid fuel; for the peak gas-turbine stations, liquid fuel is basic, since the peaks of consumption of electrical energy and of fuel coincide. However the efforts being applied for its solution are obviously inadequate, especially in regard to the accumulation of operating experience on actual GTE with sufficiently high initial gas t^0 , with the addition of the necessary additives to the fuel.

Quite promising are the special gas-turbine fuels [Ref. 7], scarcely containing any ash or vanadium, and developed in the USSR. However, for their use in GTE operating for prolonged periods, the cost of these fuels should be reduced.

The questions of the assurance, in the operating process, of the necessary working regimes of the GTE and their control do not at present limit the development of gas turbines. At the same time, the automation of the GTE is inadmissibly lagging in the Soviet Union. Many elements of the automation system are insufficiently reliable. There often are cases of the cutoff of assemblies owing to the false activation of some safety device or other. The systems of complex automation and remote control of the GTE have not yet been developed by us.

The complete and proper use of the positive qualities of the power GTE is made difficult from the fact that the planning of the gas turbine electrostations is conducted by various departments of the institute of the Heat Electrical Project with the necessary coordination, without mutual consideration of the positive and negative experience. As a result, the specifics of the GTE (the close technological connection of the individual elements, the effect, the features of the layout, the increased effect of the hydraulic resistances in the ducts, the repair and operational features, the necessity of combatting noise in the engine room and on the street, etc.) is not always considered to the required extent. The Institute of the Heat Electrical Project should control more rigidly and clearly coordinate the work of its departments. In particular, it is very important to use quickly and correctly the results obtained from successful studies on noise suppression conducted at the TET -2 of the Kievenergo.

As is apparent from the brief survey made above, Soviet gas turbine construction, notwithstanding individual difficulties in growth, in recent years has undergone substantial development. This growth could be even more significant, if we could eliminate the quite inadmissible delays in the introduction and assimilation into operation of the leading models of the new GTE, caused mainly not by technical but by organizational reasons, in which both the design-assembly organizations, as well as the turbine-construction plants, are at fault. As a result, there is delayed the test operation of the fitness of the solutions incorporated in the design, which naturally in turn hampers the further development of the gas-turbine construction.

At the present time, a number of domestic plants, on the basis of experience in the adoption of the models described above, are conducting the planning of large power GTE. For instance, the LMZ is conducting the planning of a unique (in technical and economic characteristics) cheap unitized GTE

with a power of 100 mv [Ref. 8]. The Khar'kov Gas Turbine Plant (KTGZ) is conducting a number of studies on the new GTE (gas turbine engine). At the same time, unfortunately, the question of the ways and scales of use of the gas turbine installations in the power system of the Soviet Union continues to be debatable up to the present time. Of course, one of the main use for such a circumstance is the slow assimilation of the engines already made.

Along with this, still not fully clear are the problems connected with the possibility and the economic feasibility of using, in the power GTE, various liquid fuels and natural gas, and also the most effective ways and possible scales of the use of GTE in power engineering.

The domestic and foreign developments indicated that a GTE with initial gas t° of 700-800°C is above all feasible to use as fairly simple and economical peak and heat-fixation assemblies, and also in the system of steam-gas installations for the covering of the base load. The planning studies showed that the gas-turbine TETS can be cheaper by 30-40% than the steam-turbine ones of the same power. The specific cost of the powerful peak gas-turbine stations will amount to 30-35 rubles/kv.

Under the planned considerable growth of the power systems and the tendency toward a compactness of the load diagrams, in the immediate years there will be required the construction of peak gas turbine electric power stations of fairly high power (6 X 100 and even 12 X 100 mv). Along with this, there will also find application the economic and mobile peak installations of less power (25 and 50 mv).

The appreciable lowering by 13-15% of the specific construction costs of the electric stations as compared with the steam turbine units of the same power and using the same fuel should be brought about by the application of steam-gas installations, made to include a high-pressure steam generator. In addition, these installations should furnish a fuel savings of 5 - 8%.

We also consider that the GTE of relatively low power (50, 25, 12 mv and even less) can find use as basic power installations in a whole series of actual cases: in small power systems, in remote or arid localities, near large gas deposits, etc. An example of such stations is the present construction in the Soviet Union of gas turbine stations 4 X 12 X and 4 X 25 mv. In our country, the number of such stations can be sufficiently large, no matter how the electrical networks and intersystem links have been developed.

After the solution of the problem with the liquid cooling of the blades in the gas turbines and the achievement of initial temperatures of 1200°C, and higher, the efficiency of the gas turbine installations made according to the simplest layout, exceeds 40%, while there are individual powers of 200 - 300 mv. Such installations can undoubtedly find wide application as basic ones for large electrostations in place of the steam-turbine units using the very same fuel. The technological base of the turbine-constructing plants in recent years is being improved, and new technological processing methods are appearing. This places on a real footing the creation of gas turbines with liquid cooling of the blades.

Understandably, the enumerated trends do not exhaust all the possibilities of the use of the gas turbine engines in power engineering or in other branches of the socialist economy. After the accumulation of experience in the planning and operation, coupled with the completion of a number of research projects already underway, there will become possible a further development of the GTE, and an increase in their power and economy of operation.

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USE OF PETROLEUM FUEL AND DISSOLVED ADDITIVES FOR LOWERING VANADIUM CORROSION IN GAS TURBINE ENGINES

R. A. Lipshteyn et al.

The operation of gas turbine installations using commercial fuel oils is impossible for two reasons:

at an ashing of the mazut by 0.10 - 0.15%, the flow-through part of the turbine will quickly become plugged, requiring frequent stoppages of the gas turbine engine (GTE) for cleaning (a test operation of the GTE 600-1.5 using brand 20+60 boiler mazuts showing an ash content of 0.08-0.13%, demonstrated that the turbine becomes blocked with deposits in 2-4 hours of operation so intensively that it is necessary to lower its power by twice [Ref. 1]);

the vanadium contained in the sulfurous residual fuels, especially in the presence of sodium, causes a catastrophic corrosion of the metal in the turbine's blades. (During the operation of the turbine on fuel containing only 0.001% vanadium, after 100 hours there occurred a clearly manifested corrosion of refractory steels at a temperature (t°) of 800°C [Ref. 1]).

The following ways of solving the problem of the extended and reliable operation of a GTE using liquid fuels are possible:

1. The use of low-ash fuels (with ash content of less than 0.03%), containing almost no vanadium (less than 0.0005%), not requiring a prior washing with water or the use of additives. As such fuels, we can use the distillates, obtained as a result of the secondary processing of the products of sulfurous and low-sulfur petroleums (coking distillates, heavy gas-oil from catalytic cracking etc.), and also the low-ash residual products derived from reprocessing the low-sulfur vanadiumless oils (as a rule, vanadium is contained in the sulfurous petroleums). The problems of the choice of the production technique and the tests of similar fuels were worked out in the VNINP, GROZNII and VTI.

2. The use of conventional commercial boiler fuels under the stipulation of the adoption of measures assuring the avoidance of blockage of the turbine by deposits and avoiding the origination of vanadium corrosion of the blades' metal.

At the present time, there are no developed (even under laboratory conditions) additives to a fuel, reliably avoiding the blocking of a turbine by deposits. The sole actual method, lowering the accumulation, is the reduction of the fuel oil's ash content by flushing it with water in the presence of a de-emulsifier and the separation of the water from the hot fuel in a centrifuge [Ref. 2]. Unfortunately, this step is too expensive and unwieldy, and hence is hardly acceptable for electric power stations. Evidently, this method could find application for seagoing vessels, equipped with GTE, since they are compelled to refuel in a number of countries with different fuel, including that having an increased ash content.

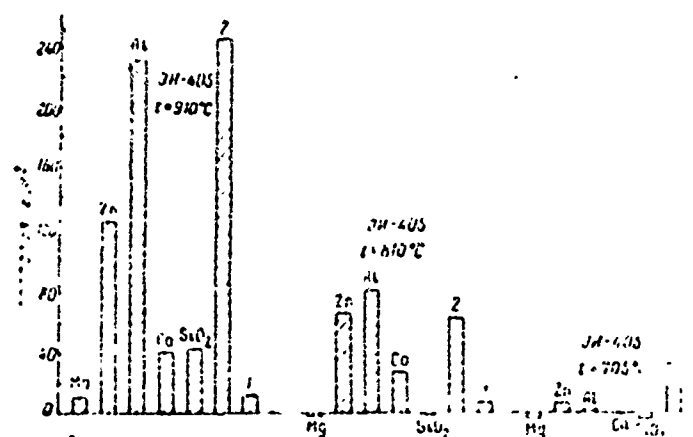


Figure 1. Effect of Additives on Vanadium Corrosion (with the exception of losses from electrolytic cleaning) of EI-405 Steel at Various Temperatures.

1 - diesel fuel, sulfurous; 2 - diesel fuel, sulfurous with 0.03% V and 0.00193% Na; the others, the same as 2, + additives.
 captions in figure: a) corrosion, g/m²; b) ZI-405; (others read as is)

More acceptable for the electric power stations, it seems to us, in addition to the basic first approach, is the following one.

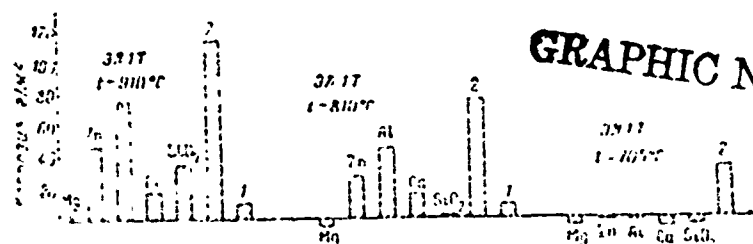


Figure 2. Effect of Additives on Vanadium Corrosion (with the exception of losses from electrolytic cleaning) of EI-17 Steel at Various Temperatures. For notations, refer to Figure 1 above.

3. The use of low-ash fuels, including the residual ones (ash content not more than 0.05%), containing vanadium and sulfur in an amount corresponding to the concentration of these elements in oil and depending on the processing technique. The obtainment of such fuels should not create any special difficulties at the petroleum refineries. There is required only the conduct

of a good desalinification of the petroleum entering to be processed. The use of such fuels for the stationary GTE does not lead to a rapid plugging of the turbine by deposits. The latter should be relatively minor and evidently their removal can be achieved by rinsing the turbine with hot water without disassembling it [Ref. 1]. However, these fuels at gas temperatures above 600°C will cause the vanadium corrosion of the blades. Therefore, the use of these fuels is possible only in the presence of a highly effective additive, avoiding vanadium corrosion.

In the capacity of such additives, the most effective have been the substances containing Mg, Zn, Si, P, Al, Ca, and Ba.

The additives are divided into: those soluble in fuel (e.g., Mg, Ca, Zn, Ba salts of carbonate and sulfo-acids, silicon- and phosphoro-organics); those soluble in water (e.g. the sulphates Mg, Al, ammonia liquor and nitrates of Ca); dry powders, insoluble either in fuel or in water (e.g. the aluminosilicates--kaolin, gallusite etc., dolomites, talcs, aluminium powder).

A number of authors [Refs. 3-9] have engaged in a study of the effectiveness of action of additives under static conditions in model fire stands and in industrial gas turbine installations.

In the present report, we have presented the results of test conducted on a fire test stand of a number of substances, soluble in fuel as additives reducing the vanadium corrosion. The fuel being tested contained 0.03% V, 0.002% Na and 0.9% S.

As metal samples, we use plates made of EYA-1T steel and part of the blades of the GTU-600-1.5 turbine was made of EI-405 steel.

The latter steel was chosen owing to its high heat-resistance and low resistance state to vanadium corrosion as a result of the presence of molybdenum in it. This permitted a limitation of the test duration to 5 hours, in the course of which during the burning of the indicated fuel, there occurred a fairly intensive vanadium corrosion (at 900°C, 100 g/m²).

The method used in conducting the tests on the stand and also its layout are described in Ref. [10].

A study was made of the ability of the naphthenates Mg, Ca, Zn, Al and also of polymethylsiloxane (technical product, PMS-15) to reduce the vanadium corrosion.

In all these tests, the ratio of metal and silicon in the fuel to vanadium equalled 3:1 (by weight).

We have presented data in Figures 1 and 2 regarding the effect of the indicated products on the vanadium corrosion of steels at test t° of 700°C to 900°C.

At 705°C under the given test conditions, all of the tested substances, with the exception of zinc naphthenate, completely prevented the vanadium corrosion. The negative weight of the loss in the metal is undoubtedly imaginary and is obtained only as a result of calculation (difference between the losses in the weight of the steel after the test, and the electrolytic cleaning

and losses in weight of the original steel specimen, not subjected to testing, after electrolytic cleaning). The negative significance of the corrosion indicates that as a result of the test, the steel proved more resistant to the electrolytic cleaning than the original sample prior to the test.

At 810°C, only the magnesium naphthenates and the polymethylsiloxanes prevented the vanadium corrosion. However, even at this t° , there occurs a certain advantage in the magnesium additive over the silicon one in the testing of the EYA-1T steel. The calcium naphthenate reduced the vanadium corrosion somewhat, but to an insufficient extent. The naphthenates of zinc and aluminum are of low effectiveness. At 910°C, only the magnesium naphthenate retained its ability of preventing corrosion almost entirely. Under these conditions, the polymethylsiloxane proved insufficiently effective.

It is interesting to note that if the activity of all the additives at a rise in t° from 810°C to 910°C falls abruptly, the ability of calcium naphthenate to reduce the vanadium corrosion is slightly diminished. At 910°C, the effectiveness of the action of calcium naphthenate and of polymethylsiloxane proved similar to each other, but for both additives, the result was not adequate.

Based on what has been indicated, additives were developed containing Mg and Si, the production of which can be organized on an industrial scale. The results of tests with these additives in a model fire stand are presented in Tables 1 and 2 (corrosion values are given in g/m^2).

The magnesium additive No. 50 [See Note] (test 36) is similar to magnesium naphthenate (at a ratio of $Mg:V = 3 : 1$) prevented almost entirely the vanadium corrosion of the EI-405 and EY-1T steels in the entire range of temperatures from 700°C to 900°C. ([Note]: Brand VTI).

The technical product No. 51, containing Si (test 33) at ratio of $Si:V = 2 : 1$, proved, similar to the polymethylsiloxane, effective only up to 800°C. At increase in the t° up to 900°C, the additive's effectiveness decreased.

The attempt to reduce the quantity of this additive (ratio $Si:V = 0.7:1$) did not succeed (test 34). At a diminished concentration, the additive's effectiveness was reduced.

The addition of green oil to the ethylsilicate (compare tests 34 and 35) decreased corrosion slightly at 900°C. Thus, the corrosion of the EI-405 steel in the presence of the green oil diminished from 43.3 to 27.7 g/m^2 , although even this was inadmissibly high.

The triple mixture of magnesium additive, the product of No. 51, and of green oil (test 39) has a high effectiveness, notwithstanding the lowered magnesium concentration ($Mg:V = 1:1$).

Conclusions

1. We have reviewed ways for solving the problem of the prolonged and reliable operation of stationary gas turbine engines using liquid fuels.
2. As additives for lowering the vanadium corrosion, there were used in a fire stand the naphthenates of Mg, Zn, Al, Ca, and polymethylsiloxane, all of which were soluble in the fuel.

Table 1

Effect of Additive on Vanadium Corrosion of EI-405 Steel, g/m²

No. of tests	Characteristics of fuel and additive	Sample temperatures, °C		
		900	800	700
6	Sulfurous diesel fuel (S = 0.9%), without ash (no V or Na).....	11.1	6.1	3.0
40-43	Diesel fuel, containing 0.03% V and 0.00103% Na.....	105.0	49.0	9.0
36	The same + magnesium additive No. 50 (Mg:V = 3:1).....	12.1	6.9	-0.3
33	The same + No. 51 silicon additive (Si:V = 2:1).....	36.2	1.3	-3.3
34	The same + No. 51 silicon additive (Si:V = 0.7:1).....	43.3	11.6	-1.2
35	The same + No. 51 silicon additive + green oil 0.5% (composition No. 54)..	23.7	13.6	1.5
39	The same + magnesium additive (Mg: V = 1:1) + silicon additive (Si:V = 2:1) + green oil 0.5% (composition No. 56)..	11.4	7.4	-3.5

Table 2

Effect of Additives on Vanadium Corrosion of EY -1T Steel, g/m²

No. of tests	Characteristics of fuel and additive	Sample temperatures, °C		
		900	800	700
6	Sulfurous diesel fuel (S= 0.9%), without ash (no V or Na).....	10.4	9.2	1.5
40-43	Diesel fuel, containing 0.03% V and 0.00103% Na.....	114.0	62.0	14.0
36	The same + No. 50 magnesium additive (Mg:V = 3:1).....	8.5	7.1	-2.5
33	The same + No. 51 silicon additive (Si:V = 2:1).....	34.9	2.1	-3.0
34	The same + No. 51 silicon additive (Si:V = 0.7:1).....	35.9	12.2	0.05
35	The same + No. 51 silicon additive + 0.5% green oil (composition No. 54).....	28.9	17.2	1.6
39	The same + magnesium additive (Mg:V = 1:1) + silicon additive (Si:V = 2:1) + 0.5% green oil (composition No. 56).....	9.7	2.85	-1.9