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Technical-economical results of industrial realization of direct current arc furnaces of new generation

Different publications represent a comparison of direct current arc furnaces made abroad with electric arc furnaces. It is fairly evidenced that advantages are insignificant, and we are fully agree with that.
However any comparison was never made with such a furnace type as General-Purpose Direct Current Arc Furnaces of New Generation ***(GPDCAF-NG)*** *that originated and made by our company. This is despite the fact that such furnaces are in industrial operation for a long time and the results of their operation are well-known at least in Russia.*
GPDCAF-NG *can not be compared with direct current arc furnaces (including those made abroad) due to the fact that they are fundamentally different in part of furnace body structure, melting methods, and production possibilities.*
GPDCAF-NG *provides high and industrial operation proven parameters that are achieved thanks to a special system of patented engineering solutions including such a part as the use of direct current arc. This is a simple solution to change alternating current arc system to direct current one to manufacture melting furnaces of minimum costs; however by this way our parameters are impossible to be realized. Therefore, the furnaces with minimized cost thanks to simple engineering solutions can not be a fair base for competition. We are not aware about any furnaces made by other manufacturers and achieved our level of performance.*
It seems necessary to give as much information as possible about new production possibilities provided by ***GPDCAF-NG*** *to specialists in the area of iron, steel and aluminum-based alloys production processes and corresponding equipment in the case that such information will sharply improve performance characteristics and production process output. In addition, this is necessary to compare them with conventional production methods and equipment.*
Russian machine-building industry modernization currently poses an urgent problem to upgrade active foundries and create new ones. Melting facilities of most foundries have become obsolete and require to be upgrading and replacing. The correct selection of new equipment and technology makes the products competitive at present time and will make it competitive in future. In this way, we have not to take into account only well-advertised and widely spread products made by well-known companies, but we need to provide their fair evaluation in comparison with other products newly developed (i.e by domestic manufacturers). It is often impossible to correct any mistakes in choice of metallurgical equipment due to its high cost and accompanying work charges that negatively influence on the future of foundries and makes them disable to be domestically and abroad competitive.
Certified name of furnaces in the range from ***GPDCAF-NG-0,5*** *to* ***GPDCAF-100*** *illustrates their general-purpose type because the whole above-mentioned product range is melted in the same furnace body structure and no replacement is required. 0,5-100 is a capacity of furnaces in tons. For foundries which are supplied with our 0,5–30 t capacity furnaces, we are ready for supply furnaces with capacity of up to 100 tons.* ***GPDCAF-NG*** *can be supplied as a separate set or by upgrading active alternating current arc furnaces.*
Key words: *electric arc furnaces, direct current furnaces, melting, steel, iron, aluminium-based alloys, foundries, mixers, ladle metallurgy.*

1. Examples of GPDCAF-NG Industrial Realization

GPDCAF-NG performance characteristics are discovered based on the results of their industrial realization and sre shown by concrete following examples.

Steel production

GPDCAF-NG-6x2 (JSC "Kurganmashzavod") [1]. Melting system consists of a power supply connected to two melting pots with capacity of 6 tons each. The system has been made by switching two arc alternating current steel melting furnaces with capacity of 5 tons into direct current supply and is in operation as-upgraded for 5 years.

Production of complex high-quality castings from various steel and iron grades in alternating current arc furnaces has been mastered at the foundry. By its performance values this foundry is one of the best in Russia and that's why the achieved advantages of **GPDCAF-NG-6x2** are the most objective.

Arc alternating current steel melting furnace (ACAF) produces iron and steel with use of regular cheap charge and own production returns in accordance with classical technologies. The possibility to solve ecological problems not by new dust-gas cleaning system but by rebuilding the furnaces has motivated this upgrade (**Fig. 1**).

Table 1 displays the results of emission measurements from GPDCAF-NG-6x2 during melting of 110G13L steel (magnesium, foundry steel grade).

Fig. 1. GPDCAF-NG-6AG (JSC "Kurganmashzavod"):
the furnace for melting of high-alloyed steels and special iron grades made by switching ACAF into direct current supply

Fig. 2. GPDCAF-20 (JSC "Tyazhpressmash", Ryazan):
25 t capacity direct current arc furnace for steel melting made by switching ACAF into direct current

The results of the table testify that the problem put by our company has been successfully resolved. In addition, the melting time has been shortened on average by 1 hour, energy consumption has been also significantly reduced. The best result is 392 KW·h/t, in the case of stable operation – 450 KWt·h/t. Average consumption of graphitized electrodes has resulted 1,39 kg/t, charge wastes have decreased from 6,0–6,5 % down to 0,5–1,0 %. All these parameters provide 50–60 kg/t of metal saving and 11,6 kg/t of manganese saving.

Significant improvement of 110G13L steel mechanical properties should be also mentioned. When melting of the metal with hardness level HB 255–269 in ACAF, the bending deflection was 2,5–2,8 and austenitic grain size class made 2–3. When melting of the metal with hardness level HB 266 in GPDCAF, the bending deflection was 3,6–4,4, while austenitic grain size class made only 1.

When 30KhML steel melting, the refining processes run on a conventional base with higher speed of sulfur and phosphorus removal. Especially high speed of de-

Table 1

Emission, g/s		Maximum permissible emission, g/s
Dust	0,3301	0,9853
Including Mn	0,0266	0,1486

Table 2

Gas content, %		
Reference specimen number	Nitrogen	Hydrogen
1	0,0145	0,00032
2	0,0125	0,00031
3	0,0150	0,00030
4	0,0090	0,00028
5	0,0011	0,00024

carbonization was observed in ore kip and made 0,1 % within 3–5 minutes. Production of castings for pressure stop devices for oil-and-gas industry that can operate at the pressure 750 atm have been mastered at the foundry with use of ordinary cheap scrap.

Gas content in a reference specimens have been investigated during melting (see **table 2**). These specimens were made from wedge reference samples preliminarily kolled by Al (0,1 mass. %).

The achieved results are standard for production of various steel grades. Very high performance parameters and quality improvement have been obtained with short time payback by upgrading the melting system with GPDCAF instead of rise of melting costs due to the new dust-gas cleaning system in the active ACAF.

GPDCAF-20 (JSC "Tyazhpressmash") [2] The furnace was made by upgrading ACAF with 20 t capacity. The furnace capacity is 22–30 tons; due to its power supply conditions, the power of GPDCAF-NG was increased only from 8,5 up to 10,79 MVA, i.e. the furnace is "slow". There is a water-cooled roof placed on the furnace, ACAF classical technologies including ore kip are applied (**Fig. 2**).

Tables 3 and **4** give comparison data resulted from the furnace upgrading.

Homogeneity of chemical composition and melting temperature, decrease of non-metallic inclusions significantly increase the supercooling rate during crystallization process and, as a result, makes the most favorable conditions for improving of the metal structure. All these parameters are also confirmed by the data from the Quality Management Center and Independent Examination of France.

Chemical composition deviations have decreased by 35 %, mechanical properties of steels for castings and forge ingots have risen by 5–20 %, non-conformity level of the state standard (GOST) requirements has been reduced by 90 %, ultrasonic inspection results have been improved by 15 % for forgings and by 45 % for export shafts. It was received that amount of melts with phosphorus content higher than 0,035 % makes 18 % for the "old" furnace and 2 % for the "new" furnace. Same, the

Table 3. Comparison of performance characteristics for ACAF-20 before and after its upgrading to GPDCAF-20

Characterictics	ACAF-20	GPDCAF-20
Dust, mg/m^3	27,2	9,9
Noise, dB (total level)	98	84
Total energy consumption for 1 ton of liquid steel / after melting point, KW·h	880/535	740/450
Liquid metal productivity, t/h	4,54	7,16
Average time for melts, hour	4,92	3,0
Average melting time for melts, hour	2,75	2,05
Total metal waste, %	7–7,5	3,5–5
Consumption, kg/t of liquid metal:		
Graphitized electrodes	14,0	2,12
FeSi	12,5	11,2
SiMn	13,0	11,8
FeMn	11,5	10,6
FeCr	11,2	9,6
FeV	7	4,7
FeMo	2,1	2,1
Lime	48,0	20,7
Fireclay (for slag formation)	12,1	2,7
Deoxidizing mixture (lime, FeSi 45, coke)	272,78,22	192,46,18
Magnesia bricks (for bricklaying)	22	12
Number of samples during a melting, pcs	4–5	3–4
Quantity of slag for a melt, tons	1,31	0,46
Annual output of liquid steel (ingots, shaped castings), tons	12000	20600

Table 4. Improvement of quality characteristics (Improvement level in accordance with GOST in %; zero values are for the period before upgrading)

Chemical composition	0	35
Yield stress	0	90
Breaking tensile strength	0	60
Elonfation	0	45
Impact elasticity	0	80
Ultrasonic inspection improvement (SEP1921)	0	45

amount of melts with sulfur content higher than 0,025 % makes 33 % in the "old" furnace and 15 % in the "new" furnace. The same changes can be noted for average values of these elements.

The results of examination of the microstructure and macrostructure of the shaft blanks made by the Central Laboratory of JSC "Tyazhpressmash" are presented below.

The examination has displayed the following results:

• Melt of steel 35, 300 mm diameter billet; macrostructure is dotted; non-homogeneity is 1 ball according to GOST 10243–75; microstructure is presented by pearlite+ferrite, grain size is 6 ball according to GOST 5699–82.

• Melt of steel 35, 380 mm diameter billet; macrostructure is dotted; non-homogeneity is 1 ball according to GOST 10243–75; microstructure is presented by pearlite+ferrite, grain size is 7 ball according to to GOST 5639–82.

• Melt of steel 45, 400 mm diameter billet; macrostructure is dotted; non-homogeneity is 1 ball according to GOST 10243-75; microstructure is presented by pearlite+ferrite, grain size is 7 ball according to GOST 5639–82.

• Melt of steel 35, 410 mm diameter billet; macrostructure is dotted; non-homogeneity is 1 ball according to GOST 10243–75; microstructure is presented by pearlite+ferrite, grain size is 6 ball according to GOST 5635–82.

When melting this type of product in the same furnace before and after upgrading, the following results have been achieved:

Before upgrading: dotted non-homogeneous macrostructure (3–4 ball), segregate zones, centerline porosity, cluster of non-metallic inclusions, microstructure 4–5 ball.

After upgrading: dotted non-homogeneous macrostructure (1 ball), no segregation, no porosoity, disconnected non-metallic inclusions, stable microstructure 6–7 ball.

The results of examinations of the melts from ACAF-20 and GPDCAF-20 furnaces made by the Central Laboratory of JSC "Tyazhpressmash" are presented below.

• Chemical composition deviation decreases by 35 %;

• Conformity of mechanical properties for cast steel improved by 35 %;

• Conformity of ultrasonic inspection requirements for all inspected forgings improved by 15 % and for export shafts by 45 %;

• Stability of the results of mechanical testing increased (data spread deviation lowered by 20 % and convergence of measurements rose by 40 %);

• Mechanical properties of the following steels improved:

25L: σ_B — by 5 %; δ — by 7 %; α_K — by 10 %;

35L: σ_T — by 9 %; σ_B — by 10 %; δ — by 7 %; α_K — by 15 %;

45L: σ_T — by 18 %; σ_B — by 15 %; δ — by 11 %; ψ — by 15 %;

20GSL (cast steel): σ_T — by 5 %; σ_B — by 12 %;

35KhML (construction cast steel): σ_B — by 14 %;

Steel 20: σ_T — by 8 %; σ_B — by 4 %; δ — by 6 %; ψ — by 9 %;

40KhMA (construction high quality steel): σ_T— by 9 %; σ_B — by 13 %; δ — by 20 %; α_K — by 20 %;

40KhN2MA (carbon steel): σ_T— by 11 %; σ_B — by 6 %; δ — by 8 %; α_K — by 11 %; ψ — by 4 %.

It was mentioned that non-conformitiy in mechanical properties for forgings and castings have been reduced: by 90 % for yield strength, by 60 % for tensile strength, by 45 % for elongayion, by 80 % for impact elasticity, while no changes have been noted for reduction.

The annual economical benefit from the furnace upgrading made totally about 52 mln. RUR, the savings per 1 ton of liquid metal for some steel grades constituted about 3600 RUR. The payback period is as long as 10 months.

The following items are recognized as the main cost-casting factors: replacement of carburizer of pig iron with steel scrap and graphitized chips (about 12 mln. RUR), charge materials cutting economy (about 13 mln. RUR), decrease of ferroalloys consumption (about 3 mln. RUR), decrease of power consumption (2,2 mln. RUR).

The above-described structure of the economical effect confirms the fact that power consumption saving can not be the main task of upgrading. The base of any performance characteristics is the costs of raw and other materials. It is also proved by **fig. 3** that new furnaces have a very short payback period to rise productivity. Ecology cost savings are not taken into account but they are also very significant.

Upgrade of ACAF-25 to DCAF-245 (Production Association "Izhstal") [3, 4]. The furnace was in operation for commercial production of R6M5 tool steel (high-speed steel). Upgrade of this furnace has decreased the level of dust and gas emissions less by 7—10 times, noise level has lowered to meet the sanitary requirements, waste of graphitized electrodes has decreased to 1,5 kg/t of melt, specific power consumption for full-power operation decreased to 12MW for melting — 420—435 kW·h with the melting time of 60—70 minutes.

The main cost-saving item is reduction of melting materials including the following savings (kg/t of metal): alloyed charge materials — 30—40; ferrotungsten — 0,3—0,8; ferromolybdenum — 0,3; ferrochrome — 1,5; ferrovanadium — 7,5. The upgrading costs have had a 7 months payback period (**Fig. 4**).

Upgrade of ACAF-5 to GPDCAF-6 (JSC "Elektrostal"). The furnace is intended for production of high-alloyed steels and heat-resistance alloys. High-quality materials are manufactured by using advanced technology and new technical solutions and all advantages typical to GPSCAF-NG have been achieved. There are no problems with metal nitrogenization. Mastered technology allows melting about 250 high-alloyed steels and alloys (**Fig. 5**).

GPDCAF-24 (Ahmedabad city, India). The furnace system is connected up with converter and is intended for production of nickel-free stainless steel. Charge materials from metallized pellets and briquettes as well as high-carbon ferrochromium are melted in the furnace.

Quality steels are produced in the converter. The furnace produces a melt with carbon content of up to 4,5 % for further processing. The furnace is equipped with water-cooled roof, wall panels, and bottom discharge facilities. The furnace is successfully mastered.

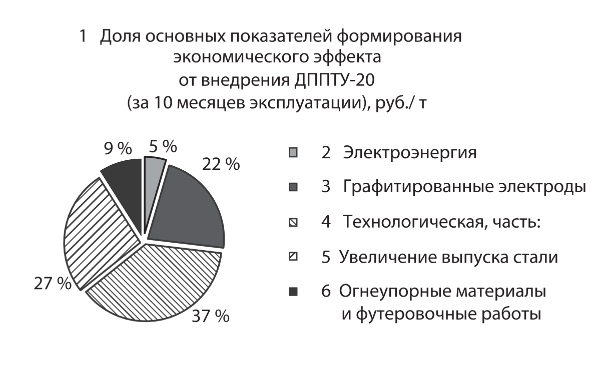

Fig. 3. Economical benefit structure:
1 — Main shares of economical benefit thanks to GPDCAF-20 (during 10 months of operation), RUR/t; *2* — power consumption; *3* — graphitized electrodes; *4* — technology; *5* — steel output increase; *6* — refractory materials and lining works

Fig. 4. Production Association "Izhstal"(Izhevsk):
25 t capacity direct current arc furnace of the new generation for high-alloyed and tool steels melting, upgrading from ACAF-25

Fig. 5. JSC "Elektrostal"(Elektrostal city, Moscow region):
6 t capacity direct current arc furnace made by switching ACAF to direct current

Melting technology is different from accepted ones being in use. Charge materials in the form of pellets and briquettes are loaded into the furnace in one step. After metallization of briquettes to the required level, reduced metal is completely transformed to a melt, while the output (relating to the weight of briquettes) makes totally 93 % due to reduction of non-reduced Fe oxide in charge materials.

The furnace in operation demonstrates a very low level of dust and gas emissions, very high quality of charge materials at the end of melting process, low (for such melting processes) power consumption (610 kWt·h/t). Production cost for steel was 25 USD cheaper in comparison with the costs when producing by ACEAF (electric arc furnace) equipped with a ladle furnace and of 150 t capacity converter.

The melt consisting of iron alloyed with copper and chromium is passed from the furnace to the converter with oxygen-argon blowing for alloying finalizing or directly to continuous casting machine.

As required by the Indian customer, the ladle furnace was added to the technological process. Our opinion that it does not make any sense has been further confirmed (**Fig. 6**).

Iron production

JSC "Kurganmashzavod" [*1, 5*]. Iron melting in direct current arc and alternating current arc furnaces has been mastered. Melting productivity in GPDCAF-6x2 is much higher than in alternating current furnaces.

Production of synthetic iron without usage of pig iron and cast iron has been mastered in the furnace with 5 t melting capacity of metal with calculated carbon content 2,2 % in metallized charge materials. Carburizer is presented by graphite crumbs of crushed electrodes (3–10 mm in fraction, 96 % carbon content), that are loaded on the furnace bottom after previous melting has been discharged. Carbon recovery makes 75 %, the time of melting, heating, carbonization and element finishing makes 80 min; energy consumption in the case of two-shift operation and long idle periods is 630 kW·h/t. Pig foundry iron in charge materials has been replaced by steel scrap of 2A grade in accordance with to GOST 2787–75. Cost of such charge materials are lower than cost charge materials with pig iron by 4000 RUR/t. Other charge materials are presented by own production returns.

Fig. 6. Electrotherm Ltd. (Ahmedabad, India):
25 t capacity direct current arc furnace for steels

The final chemical composition of synthetic iron was as follows: C 3,60 %, Mn 0,96 %, Si 2,18 %, S 0,027 %, P 0,086 %. Taking into account carbon and silicon content, the iron meets the requirements of of GOST 1412–85 for SCh15 grade (grey iron). But its mechanical properties (σ_B = 11,0 kg/mm^2, HB = 229) correspond to SCh20 grade of grey iron. Such high improved properties are provided by technological possibilities of GPDCAF-NG.

Production of SCh15 – SCh30 grades of gray iron and VCh40 – VCh70 grades of high-strength iron in ACAF and GPDCAF-6x2 has been also mastered by the company.

Initial iron for high-strength grades is melted in the furnace with basic lining. Active slag processes and melt mixing provided sulfur content not more than 0,001 %, allowing thereby to reduce consumption of magnesium alloying composition to 1,0–1,2 %. Mechanical properties are noticeably improved. For example, iron having such composition as C 3,58 %, Si 2,13 %, Mn 0,68 %, S 0,007 %, P 0,06 %, Cr 0,17 %, Ni 0,0 5% is characterized by tensile stress 68 kg/mm^2, and elongation 12 %.

JSC "GAZ" GPDCAF-12. The furnace is mounted at a steel casting shop having no funds to produce iron castings. After rising the prices for pig iron and cast iron, the furnace was re-oriented to produce charge billets from syntethic iron for cupola-furnaces (**Fig. 7**).

Iron with carbon content up to 3,6 % is produced by melting of briquettes from steel sheets and coke in small fraction fines during thermal processing of charge materials and heating of melt. The melting time makes 80 minutes, melt weight is 12 t, economical benefit is 3000–4000 RUR/t.

GPDCAF-3x2 at JSC "Kostromamotordetal" [*6*] Melting system at this plant consists of two furnaces with capacity of 3 tons each and operates with a 5,5 ton load for turn-by-turn operating furnaces. The system melts iron chips with cooling liquid. Iron is melted in induction crucible furnaces with 10 t capacity that receive melt from DCAF having productivity 1000 t/month. This is

Fig. 7. JSC "GAZ" (Nizhniy Novgorod, Russia):
12 t capacity direct current arc furnace for melting steel and iron, full set supply

Fig. 8. JSC "Kostromamotordetal" (Kostroma, Russia): the furnace for iron chips melting, full set supply

the first time when the equipment has allowed industrial waste-free processing of iron chips and resolved the serious problems with iron recycling (**Fig. 8**).

Availability of large amount of contaminating components in iron chips with cooling liquid, sand etc does not allow to determine the output by weighting. However, it can be evaluated by comparison of final chemical composition with the standard technical requirements for chips metal (see **table 5**).

Actual content of C, Si, Mn is higher than listed in the technical requirements; it is obviously resulted by reduction of cooling liquid materials and sand from slag. Low sulfur content is determined by the classical desulfurizing in GPDCAF-NG. The difference between the price of chips (about 2000 RUR/t) and slag costs for iron melting (about 12000 RUR/t) totals the economical benefit.

Installation of second power supply unit to replace induction crucible furnace and transfer the iron production to GPDCAF-NG is currently under discussion.

Melting of aluminum-based alloys and alloying compositions

Technology and equipment for melting aluminum alloys in arc and plasma furnaces had been successfully mastered for the first time in the USSR in 1986–1987 [7]. The objective of the works was to provide production of high-quality castings from secondary aluminum alloys, and it was successfully achieved. At present time many technological processes connected with melting of high-quality castings, recycling of wastes of aluminum alloys (including chips, slag removals, steel-containing charge materials etc), melting of different Al-based and deoxidizer-based alloying compositions have been successfully put into operation in GPDCAF-NG. Construction and operation principles of such furnaces do not differ from those that used for melting of steel, iron and other metals in GPDCAF-NG.

Possibilities of melting of aluminum alloys have been demonstrated by industrial application of GPDCAF-0,5x2 melting systems. Such system can be supplied in two set options: with power supply unit S = 0,84 MVA and with one or two melting pots. The prototype of such furnace was plasma-arc furnace induction steel melting furnace PSP-06/07 [7]. It was installed at the Kovrov Electro-Mechanical Factory (Kovrov, Russia) to replace four furnaces for induction aluminum melting IAT-0,4 due to its high productivity [8]. Service time of rammed lining is 13-14 years, a furnace roof is replaced in 6–8 months. End-to-end power consumption for foundry production was 2800 kWt·h/t in the case when induction furnace IAT-0.4 and has been decreased to 800 kWt·h/t after putting the new furnace in the practice. The high power savings were provided by sharp decrease of rejects in production of complicated castings, by significant time improvement for aluminum melting in the whole production cycle to 20 min, by low energy consumption (340 kWt· h/t) during melting directly in the furnace.

GPDCAF-NG melting ensures metal of high quality. For example, AK7ch alloy (aluminum alloy with silicon) that is produced in commercial scale, corresponds to the requirements of GOST 1583–94 in its chemical composition and even exceeds them in its mechanical properties. Reference standards for this alloy cast in metallic forms and heat-treated demonstrate tensile stress not less than 216 MPa, elongation not less than 2 %, Brinell hardness not less than 94,9 BA, while silicon content varies in the range 6,15–7,15 %, magnesium content — 0,25–0,4 %, ferrum content — 0,1–0,3 % and structure is characterized by for high dispersity of nonmetallic inclusions. Hydrogen content makes 0,1–0,2 cm^3 /100 g of metal, and final castings always have porosity level according to 1 ball (GOST 1589–93).

High quality of aluminum alloys can be demonstrated by the example of AL9 (aluminum cast alloy). It was subjected to four-step melting process and holding time during the last melting constituted 40 min (mixing mode). All melting and holding processes did not practically change the chemical composition of this alloy, it was as follows: Si 7,1–6,9 %; Mg 0,25–0,23 %; Fe 0,43–0,4 1%. After 40 min holding, Fe content decreased to 0,32 %. No other actions to improve the metal quality have been taken. The alloy met the requirements of GOST 2685–75 in respect to its chemical composition and mechanical properties and its structure represented higher dispersity of non-metallic inclusions. Its tensile strength in cast state was 160 MPa, elongation — 2 %, hardness — HB 50; hydrogen content — 0,2–0,4 cm^3 / 100 g of metal.

Table 5. Melt primary melt chemical composition

Name of values	C	Si	Mn	S	P
Values of standard technical requirements, %	3,10–3,30	1,80–2,00	0,30–0,80	≤0,05	0,11
Actual values, %	3,63±0,8	2,28±0,13	0,4±0,04	0,007	0,11

GPDCAF-NG is the only system where intensive removal of hydrogen and non-metallic inclusions occurs during the melting process. Fast speed of the melting process allows to produce a melt without Fe saturation in the case when aluminum melting have steel small size parts. The melt always accompanies with porosity level of the 1 class (according to the GOST 1589–93), while hydrogen content, as a rule, makes 0,1–0,2 cm^3/100 g of metal (for several cast alloys it can reach at maximum 0,4 cm^3/100 g of metal). These results make possible to produce quality castings from secondary aluminum with less expenses. Thanks to exception of many technological operations [5] and quality improvement of alloys, technological process costs go down by 5 times compared with induction melting costs and by 15 times compared with gas melting costs, while aluminum losses are cut down by many times.

The specialists of Zavolzhsky Motor Works have conducted pilot melts in DCAF-0,5 at the Kovrov Electrical Mechanical Factory. The alloy resulted from melting AK7ch returns left from casting production at Zavolzhsky Motor Works has been investigated; in the induction channel furnaces, where remelting leads to dramatic quality deterioration. The DCAF-0,5 load weight of the returns with remained steel elements made 427,3 kg. Melting and short-time holding resulted in production of 398,3 kg of aluminum alloy. Losses in slag, metal wastes and steel element sludge on the furnace bottom constituted 6,8 %. The final alloy after the pilot melts has completely met the requirements of GOST 1583–93. The samples taken from during the pilot melts have demonstrated the following mechanical and technological properties (see **Table 6**):

Table 6. Mechanical and technological properties of AK7ch alloy

Alloy properties	GOST	Top sample	Bottom sample
1. Elongation, %	2	4	2,7
2. Tensile strength, kg/mm^2	15	18,5	18,35
3. Hardness, HB	50	68	72
4. Hydrogen content, cm^3/100 g of metal	–	0,1433	0.1319
5. Gas porosity, ball	–	no	1
6. Castability, mm	–	802	775

GPDCAF-0,5 for "Aluminum Alloys of Estonia AS". The furnace is intended for melting of aluminum alloys from secondary aluminum, including chips and slag. Capacity of the furnace was increased up to 1000 kg. In addition to aluminum alloys, production of alloying compositions and deoxidizing agents has been conducted. The bottom lining made of magnesite allowed to heat a melt up to 1720 °C and made solving the task more easy. The following alloying compositions have been produced: AlSi (10–60); AlFe (10–80); AlTi (5–70); AlSr, AlMn etc. This project envisaged installation of GPDCAF melting furnaces and mixer with capacity of 9 t, but it has not been completed. The operations were designed to be provide scrap sorting and separation of steel small size parts, as well as consequent removal of non-metallic inclusions and hydrogen during melting.

Followed by fast melting (15 min), the melt had to be poured into a ladle where consequent chemical analysis will be conducted. In the case if the alloy meets the requirements of chemical composition in part of impurities, than the ladle had to be poured into a mixer. If significant deviations from the standard chemical compositions have been observed, metal was used as a material for special orders for tailor-made alloy with such chemical composition. The mixer that is heated by arc discharge with consequent melt mixing will provide alloy finishing in order to obtain the preset chemical composition and its pour in ingots afterwards. It is shown that large mixer capacity mixer will make more easy to solve the task of composition averaging. Easy alloy-to-alloy transition is ensured by possibility of full mixer discharge at every moment.

As a further step, a mechanical device with smaller bath capacity could be connected to power supply unit of the mixer to produce small volume orders or alloys with special properties. It took about 1 hour to produce the alloy in the furnaces without mixer, including 15–20 min for the melting process. The rest time was required to obtain the preset chemical composition in the furnace. However, the process demonstrated high level of performance characteristics even for the above-mentioned conditions. The alloys were characterized by high quality that is normal for GPDCAF-NG, power consumption made 350–400 kWt·h/t, including 290–310 kWt·h/t for melting process and 170 kWt·h/t for remelting of heavy-oiled charge materials using "hot" oxygen.

The produced alloys cast into charge billets have completely met the technical requirements of special steel grades regarding their chemical composition and mechanical properties; they also were characterized with high density and hydrogen content in all examined samples didn't exceed 0,4 cm^3/100 g. They can be used for production of high-quality cast billets in the case of availability of corresponding equipment (**Fig. 9**).

GPDCAF-0,5 for JSC "Stupino metallurgical company"

High quality of aluminum alloy casting (e.g. in automotive wheel production) have been confirmed (**Fig. 10**).

Direct current arc mixers

GPDCAF-12x2 JSC "Yaroslavsky motor works"

It is installed for heating and holding of iron molten in cupola furnaces. It has two mechanical parts connected to the same 4,5 MVA power supply unit. The loading capacity of these mechanical parts is 12 t for each and hour productivity during heating up to 100 °C is 40 t/h. The power supply unit allows to melt metal in case of its

Fig. 9. Furnace for melting of aluminum alloys and alloying compositions at "Aluminium Alloys of Estonia AS" (Tallinn, Estonia). Full set supply

Fig. 10. Universal direct current arc furnace for melting of steel, iron, aluminum-, copper-, nickel-, cobalt-based and other alloys in GPDCAF-0,5 at JSC "Stupino metallurgical company". Capacity 0,5–1,2 t

freezing and provides parallel operation of both mixers. The mixer can be also used to melt steels and aluminum- and copper-based alloys.

According to the concept of the EKTA Scientific and technical company, two mechanical parts are supplied. It supposes possibility of applying different technological processing of melt in mixers one after another — desulphurizing, dephosphorizing, hydrogen content control, alloying, fine adjusting of chemical composition and refining with use of active slag processes. These possibilities allow to produce high-quality metal from regular charge materials after melting in a furnace with low technological level or during processing of scrap materials that have been classified during pouring from GPDCAF-NG of smaller capacity. The mixers have very simple construction and do not have any problems with refractory materials and lining operations. They are economically efficient, safe and can operate with complete discharge of metal.

The new heating method can be applied to distributing furnaces and pouring units. They can repeat the technological possibilities of induction heating furnaces, but, thanks to the use of arc heating, they can be more universal and safe. EKTA Scientific and technical company is ready to supply mixers with different capacities and power ranges, according to the requirements of customers and to cooperate with different companies for establishment of casting complexes.

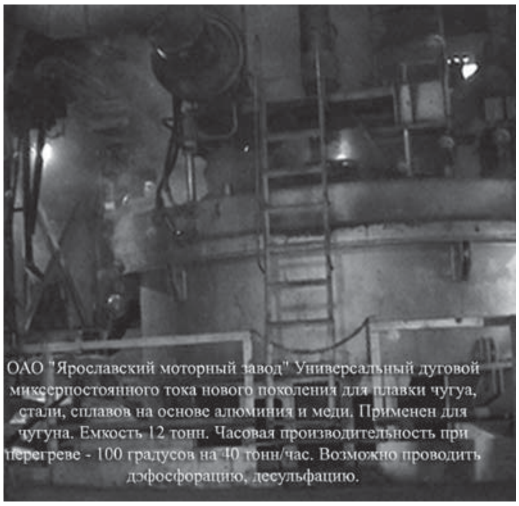

Fig. 11. Universal direct current arc mixer for melting of iron, steel, aluminum- and copper-based alloys at JSC "Yaroslavsky motor works". It has capacity is 12 t, it is used for iron melting, provides desulphurizing and deposphorizing. Hour productivity during heating up to 100 °C is 40 t

Based on the above-described examples it can be concluded, that equipping foundries with GPDCAF-NG allows to produce high-quality metal from regular cheap scrap and widely spread refractory products. Using the equipment makes it possible to avoid:

• organizing mass production of special refractory materials or importing them from abroad;

• industrial processing of scrap with separation from its content high-quality, chemically pure and other expensive metals suitable for induction melting;

• heat treatment or other processing for organic fertilizer and moisture removal before melting;

• establishment of complicated system for ladle treatment.

In relation to electric arc furnaces + ladle furnace treatment, use of GPDCAF-NG provides favorable conditions for casting production facilities meaning fulfillment the Kioto protocol agreement and labour protection requirements. It also allows to solve effectively the power- and resource saving problems, to organize flexible production facilities with any required work schedule, to agree melting and casting processes and to ensure technologically universal approach, with significantly cutting down pf capital expenses and operation costs (**Fig. 11**).

Prospective steel-making processes

The prospective direction of application for mixers is decarburizing and refining processes for iron poured in the mixers from the blast furnace. Ore concentrate, ore pellets, metallized pellets with low metallization degree can be used for hydrogen oxidation.

The technology makes it possible to perform melting with intensive magneto-hydrodynamic mixing and to obtain a slag-melt with advanced surface due to mixing process. It also allows to continue blast-furnace process with full use of carbon and involving in the process additionally up to 40 % of ore concentrate, in particular in the form of metallized pellets with metallization degree not higher than 60–70 %. Independent heating makes it possible to conduct the process within the preset temperature limits that permits to oxidize iron impurities (such as magnesium, silicon etc.) at relatively low reaction temperatures and to hold them in the melt at the process temperature higher than 1600 °C.

The process can be realized in the mixers of any capacity with limited energy supply sources. For example, 25MVA power unit can be mounted at the mixer with 100 t hour productivity of technical iron. DCAF can also be used for energy supply of the mixer or converter with synthetic iron charging, manufactured via steel scrap carbonization.

Such method has been already put into practice at JSC "GAZ", where synthetic iron is molten in GPADCAF-12 for further charging into cupola furnaces. Steel melting with liquid charge from a mixer is also possible in low power DCAF equipped with the feeding system for alloying additives.

The technological chain containing GPDCAF-NP of new generation for synthetic iron production or "blast furnace – mixer" combination oriented on iron reduction process by iron carbon and GPDCAF-NP of new generation for steel production is based on the furnaces already operating in the industry. However, it is realized at present time only partially, e.g. at JSC "GAZ", "Electroterm" (India), JSC "Kostromamotordetal", JCS "Tyazhpressmash". The new technological process has productivity not less than provided by the existing metallurgical facilities, but it can be characterized by substantially higher performance characteristics and atmospheric emissions lowered by hundred times.

As an option, GPDCAF-NP of new generation can be applied for processing of steel scrap into synthetic iron for charging a converter. This would significantly improve the process efficiency due to complete or partial replacement of pig iron by synthetic iron. Such process with annual productivity of 100 kt has been realized by the EKTA at Mardia Steel, India. Metallized pellets and briquettes, steel scrap, carburizer, ferroalloys were used as charge materials to produce nickel-free stainless steels.

1. GPDCAF-NG Technological Conception

As an alternative to the current melting systems, the EKTA specialists have developed a range of general-purpose DC arc furnaces of new generation (GPDCAF-NG) which have been applied to master the melting of steel in any grades such as Steel 3, Steel 40, KhML, 5 KhNM, 4Kh5MFS, 110G13L, R5M5, R16, stainless chromium-nickel steels such as 10Kh17N13M3T, 06Kh20N14C2; nitrogenic steels such as 03Kh17GDAMB; nitrogen-free stainless steels; die steels such as 4Kh5R2FS; high-chromium steels such as 95Kh18, special steels and alloys such as 14Kh20N25V5MB-P and other similar alloys; grey iron of SCh15 to SCh30 grades with grade increase from P45, F55 up to P in SCh30, high strength iron of VCh40-VCh70 grades etc., aluminum-based alloys such as AL-9, AK7ch, AK12-18 and other master alloys based on aluminum such as AlSi 20-60, AlMn and others; deoxidizing agents such as FeAl20Ti, FeAl30Mn30 and other alloys based on copper; as well as reducing melting processes for nickel, cobalt, magnesium, and other metals. General-purpose mixers have been developed for iron, steel, alloys based on aluminum and copper.

The technological concept of the new furnaces is based on the condition that they would be able to perform all the classic operations known from the metallurgical process theory under the conditions as near as possible to the ideal ones. In other words, any local overheating of metal, gas exchange between furnace space and surrounding environment, melting loss should be suppressed in the heating and melting processes. Controlled melt stirring, temperature and chemical composition of the slag with advanced slag-metal interaction surface provide thanks to the mixing provides homogeneity of the chemical composition and temperature during all the periods of the melting process. In addition, it provides practical prevention of intrusion of materials from heating sources into melts, possibility of reducing and oxidizing processes, suppression of metal aeration by gases (such as nitrogen and hydrogen), active dephosphorizing and desulphurizing in iron and steel melting, removal of non-metallic inclusions and solved gases from the melt, dispersion of residual non-metallic inclusions and other processes. All of the above-listed processes has resulted in high-quality metal melted in our furnaces in industrial operation that will be displayed below with particular examples.

To realize the accepted technological concept, general-purpose DC arc furnace of new generation (GPDCAF-NG) has been developed.

2. Basic DC arc furnace of new generation

The mechanical system is based on typical construction of AC arc furnaces including: steel case lined with refractory materials which are selected depending on the requirements of a particular technological process; water-cooled roof lined with refractory products; case door for slag discharge and other technological operations; mechanism for graphitized electrode moving; tilting mechanisms for melt pouring and slag discharge, electrode moving, roof lifting or bath evacuation for charge loading; a door opening mechanism. The furnace construction has been thoroughly tested for many years in ACAF operation. It does not have water-cooled elements under and around the melt, i.e. it is explosion-safe. Any refractory products for this furnace don't have met any special requirements. The construction is simple, durable and reliable in operation. It allows to conduct reducing and oxidizing processes, cold and hot maintenance works and does not take long time for replacement during capital repair. The charge materials melting and melt heating processes are performed by arcs burning between graphitized electrodes and melt.

Bottom electrodes are located at the bottom of DC arc furnaces to conduct the current to charge materials and melt. In ACAF, three roof electrodes are mounted through ACAF roof, there are no bottom electrodes. ACAF normally makes full melt discharge and allow to produce high quality steel (iron) using cheap scrap and inexpensive high-carbon ferroalloys. Scrap heating inside or outside the furnace improves the melting performance characteristics, but creates to environmental problems.

3. Disadvantages of ACAF

ACAF and DC arc furnaces, that are manufactured by many companies, have many advantages, but also are characterized by very serious disadvantages. They are caused by the fact that the problems of melt mixing, energy transfer from arc into the melt and arc discharge control are not solved. The above- mentioned reasons arise high loss of charge materials and ferroalloys (4,5–6 %), of graphitized electrodes (4,5–17,0 kg/t), local overheating of melt under arcs and narrow application field (for example, the ACAF cannot be used to melt aluminum alloys). As well, high gas and dust emissions and high noise level, drastic variable features of power supply system, flicker, high electric energy consumption (650–900 kW· h/t), low productivity and large volume of manual labor are observed.

Nevertheless, ACAF are currently in operation at many Russian enterprises, with production (in particular, for steel castings) much higher than at modern induction melting furnaces — thanks to ACAF technological possibility to melt high-quality metal from cheap charge materials. The ACAF profitability dramatically decreases when performing the ecological requirements to protection of the environment and when installing new power supply systems to improve the electrical energy quality. The costs for gas and dust cleaning systems and filter compensation followed by installation and further maintenance works increase production costs. Just a transfer of ACAF to direct current supply is not repaid because its only results in reduction of flicker and consumption of graphitized electrodes, but accompanies by significant expenses.

At the same time, DC arc furnace designed with taking no attention to interaction between arc discharge and metal, can give a rise to a sharp increase of rejects due to metal saturation by nitrogen from furnace atmosphere. For example, plasma and DC arc furnaces are in operation at JSC "Mechel" (Chelaybinsk), where more than 240 grades of special steels and alloys had been mastered with the assistance of the author. The reconstruction performed by the work's specialists together with the JSC "Acond" was unsuccessful and resulted in almost complete loss of all the furnace technological possibilities and dramatic increase of rejects due to nitrogen saturation.

4. Modern foreign and domestic trends of ACAF reconstruction

At present time, development and upgrade of the ACAF technological processes by the foreign and domestic companies is undertaken in the direction of implementation of duplex-process based on melting of charge materials in combined ACAF and steel production in ladle using the arc heating. Such technology seems to be disputable for usage in metallurgy and is unacceptable for machine-building metallurgy.

The publication [8] can be observed for better understanding this point of view. It describes the most modern electric arc furnaces (EAF) designed to produce melt for consequent ladle treatment. We present the high-capacity steel melting furnace but with smaller capacity furnace, offered for the machine-building. The furnace capacity is 160 t, melt weight is 120 t, the metal balance in the furnace is 40 t, the output is 90–91 %, and transformer power is 170 MV·A. To provide acceleration of melting, to protect furnece walls, to reduce heat losses and to save electric power, the furnace operates with four 3,6 MWt lance burners; two 3,6 MWt gas-oxygen burners are used for heating of charge materials; three oxygen lances (with oxygen consumption as large as 400 m^3/h) for CO additional burning in furnace gases; three lances for carbon powder blowing with rate 70 kg/min.

Consumption of materials and energy for 1 t of liquid steel (to speak more exactly - of technical iron, because steel itself will be produced in the ladle) makes: 340 kWt·h/t for technological power; 1,2 kg/t for electrodes; 35 m^3 for oxygen; 5 m^3 for natural gas; 10 kg for carbon containing materials in charge; 7 kg for blown-in coal powder for slag foaming; 40 kg for lime; 90–100 kg for charge as a fuel.

It is very important to make the right choice of charge materials to melt steel in electric arc furnace due to the fact that 70 % of costs are taken by metallic charge materials. It is stated that cheap slag it is not mandatory prerequisite of low costs at production stages, because variation of technological energy costs depending on scrap quality should be taken into account. From this point of view, the best charge materials are as shredder-processed. Metallized pellets and briquettes with 5 % preferable carbon content and high degree of metallization are considered as the best charge materials in melting of the metal with low level of impurities. It is shown that melting in electric arc furnace is accompanied with up to 20 % of losses of power supply to the furnace with waste gases as chemical and physical heat. In addition to much larger amount of waste gases (in comparison with ACAF) it presents the ecology and heat utilization problems. As stated by [8], electric arc furnace should be equipped with a shaft reheating unit for charge materials (including briquettes) to utilize heat of waste gases and to catch partly dust.

Intensive heat conditions of operation in the furnace and gas outlet sections make it necessary to use widely water-cooled elements with high level of heat removal.

The gas and dust cleaning system should be equipped with filters, lined chamber for additional burning of waste gases, quenching chamber, absorber for removal of toxic impurities in waste gases filled with activated coal (0,3 kg/t of steel). The successful operation is possible only in the case of usage the advanced auxiliaries and automatic control systems for technological processes. Therefore, only oxidizing process that can be performed in the electrical arc furnace. Other technological processes are conducted in the ladle furnace and require supply of the following technological components: gases (oxygen, argon); slag-forming additions or synthetic slag; powder-like slag-forming materials; deoxidizing agents (including aluminum wire); ferroalloys. Such processes as losses of charge materials and graphitized electrodes, consumption of electric power and refractory products are occurred in the ladle furnace; gas cleaning is also required. The real high quality of metal can be achieved via its vacuum processing.

5. Disadvantages of "Electric arc furnace + ladle furnace" process in machine-building metallurgy

The authors of the above-mentioned article [8] do not present any data concerning electric power costs required by auxiliary operations, such as operation of gas and dust removal system and ladle furnace, while they make, according to rather minimal estimations, 100–150 kWt·h/t, with reaching the level 440–490 kWt·h/t for electric power consumption. However, it is impossible to melt steels without duplex-process and powerful gas and dust cleaning system. Wide use of chemical reactions heat is in contradiction with the requirements of Kioto agreements and increases CO_2 emission in the atmosphere by many times. The authors also did not cite any data in respect to noise level which exceeded 100 dB.

The equipment taken for comparison in the above-mentioned article is actually the most effective for its equipment group and any deviation from its technical solutions will worsen the performance characteristics.

Let's suppose that you want to modernize the plant where ACAF is in operation. In this case it will be necessary to purchase electric arc furnace, ladle furnace, mechanization and automation facilities, to build oxygen station, cooling station using chemically cleaned reused water, to supply natural gas, to solve noise protection problem, probably to improve the electric power supply system, to revise the requirements to lifting equipment, to match the furnace operation with operation of casting equipment (because the electric arc furnace can not be used at non-continuous mode), to solve slag removal problem (the output is 90–91 %, and practically all the alloying additions including toxic elements transfer from charge materials into slag). All above-mentioned and many other costs should be taken into account in calculation of the capital assets.

These costs are much higher when replacing open-hearth furnaces.

If the conditions are such that the replacement is necessary and you are offered to purchase a ladle treatment as a first, the offer shall include also further purchase of the electric arc furnace.

As for metal production in GPDCAF-NG, it is not necessary to purchase ladle treatment because its usage can deteriorate the metal quality.

Electric arc furnace and ladle furnaces are united in the consequent technological line. Let's suppose that one of the components of this high-productivity equipment line would be out of operation (sometimes such matters happen), and the whole production process will stop.

There are a lot of grades of iron and steel in production for machine-building metallurgy. The presence of remained liquid metal in furnace makes it difficult to provide required transfer from one grade to another one.

Casting is accompanied with a large amount of metal returns (up to 40–60 %) from which 10 % will burn during melting in electric arc furnace (including all the main alloying elements), i.e. purchase of fresh ferroalloys will be rather actual.

Charge materials should include large amount of carbon to provide operation of oxygen lances. i.e. it will be required to introduce large amount of iron that costs much higher than steel scrap does.

When calculating the production costs, it is necessary to estimate the following parameters: auxiliary materials (oxygen, natural gas, lime, water); gas cleaning system maintenance; burnt charge materials etc. If all above-mentioned will be re-calculated in electric power costs, it can be revealed that the costs of burnt charge materials for production of carbon low-alloyed steel will correspond additional 8000 kWt·h (for metal loss 10 %, lowered cost of charge material 8000 Rub/t, electric power cost 1 Rub/kWt·h). It is evident from the chosen melting method is high resource- and power-spending, especially for melting of high-alloyed steels and iron.

When producing cast products, the metal is poured out into molds, and further metal forming does not take place, in contrast to metallurgical production. Under these conditions, possibility of production of high-quality steels in the " electric arc furnace + ladle furnace" combination is doubtful: other types of furnaces are used for this purpose in the world.

6. Induction furnaces

Induction crucible furnaces have a melt being inside of water-cooled induction block and isolated from it by lined crucible. Induction channel furnaces have a melt being in crucible and heated in lined channels inside of water-cooled induction coils. Any damage of rather thin lining can always result in water ingress under the melt. In such a case, intensive emission of melt from the furnace or explosion may happen.

The companies manufacturing induction furnaces have developed accident diagnostics devices to prevent from the damages, but the principle of induction furnace construction is based on such a potential risk of damage.

The attempts to increase capacities of induction furnaces rise the risk of negative consequences, as well as usage of induction furnaces for "hot" slag processes (which always promote the lining attack).

The second source of danger in melting in induction furnaces is that the main part of charge materials has to be loaded into a melt. It is caused by the fact that volume of induction furnace chamber is close to melt volume by the end of the melting, while density of charge materials is lower than melt density by several times. Ingress of moist charge materials, pieces of ice, any volumes filled up with water into melt can also cause the explosion. The problem can be fully solved by use of additional equipment (as a rule, thermal equipment), to heat charge materials before induction melting; however, principle possibility of damages still takes place. That is why induction furnaces are highly explosion-dangerous by their basic principle, but in spite of this fact they are widely used thanks to their possibility for melting and holding of wide range of metals and alloys, when any alternative equipment is not available.

Currently induction furnaces are the heart of production activity of the leading foreign and domestic companies. A lot of technologies and (taking into account their practical use) special casting and foundry equipment have been developed and mastered; significant investments have been made in their improvement and upgrading. Competition between the largest manufacturers of induction melting furnaces stimulated intensive advertising and forming of public opinion. Therefore dangerous environment during operation of induction furnaces has been got into the habit.

In these conditions it is very important to develop and master alternative and principally safe equipment which can provide the same result as induction melting and even exceeds it. Its is clear that we should avoid any hard processes and events, if we can do it. The additional argument is that induction furnaces have very serious disadvantages concerned with their performance characteristics.

Induction furnaces are technologically passive and can't provide conduction of almost all technological procedures of metallurgical processes. Induction furnaces are able to melt or re-melt metals with some degradation of properties of initial charge materials. The quality of finished metal is completely depended on the quality of initial raw material; it respects to chemical composition of charge materials. The induction melting does not allow any pollution of organic compounds, the presence of moist charge materials. To make the induction melting relatively safe in operation, specially developed refractory products must be used and exact lining and operation requirements should be followed. Special industrial system for charge materials preparation and quality refractory materials productionhas been established in the developed countries, but it is not present at full in Russia. Scrap should be strictly graded in the process of charge materials preparation and also cleaned by detergents or heat treated; it is not rather ecological safe and expensive operation. In many cases other types of melting furnaces are used for production of special billets for further induction melting.

Another direction is external technological processing applied to a melt after induction melting. to remove all harmful impurities and with the purpose of refining. A lot of types of equipment and materials that are expensive as a rule and harmful to the environment have been developed for the above-mentioned processes. That is why, when calculating the performance characteristics for induction melting, all the above-listed and other factors (such as raw material cost, expenses for its preparation to melting and ladle treatment should be taken into account.

Power costs for induction furnaces operating at industrial and high frequency are not of great importance against the other expenses. However, the great amount of induction furnaces (manufactured in the USSR and operating at industrial frequency) for mass production purposes stayed idle due to a lack of orders under the market conditions after the Soviet period's collapse. Continuous holding of some liquid metal has resulted in very high specific electric power consumption (1500–2500 kWt·h/t), e.g. in iron making. Replacement of these furnaces by ones operating at higher frequency eliminates the defect but other alternative possibilities should be taken into attention when looking for new equipment.

When calculating the capital investments, attention should be paid not only to the price of furnaces, but also to the costs of other equipment for charge materials preparation, on expenses of auxiliary materials, ladle treatment, cooling system, ecological investments, in particularly for pre- and after-melting production process management. But the most important is to provide safe production.

7. DC Arc Furnaces New Generation Conception

Developed and patented system of engineering solutions and based on them technical-economical parameters significantly exceeding the main characteristics of modern melting equipment substantiate actually only parameters of the equipment developed by EKTA.

It was above said that ACAF is the base construction of GPDCAF-NG, all ACAF advantages and disadvantages were listed and the technological concept of GPDCAF-NG was formulated. The new engineering solutions developed and mastered by EKTA for arc furnaces and allowing to consider them as the new generation equipment are presented below.

Metal heating sources. Electric power without attracting any other heat sources.

Furnace safety. The ACAF construction without water-cooled elements under the bottom lining has been taken as the base. Bottom electrodes in form of steel sheets located in the depth of the lining and welded to a copper-steel base are used for current supply to charge materials. The copper-steel base is cooled behind the bottom's case. To protect the bottom electrode from flash arc, the active anti-flash arc protection system is mounted on the furnace case between the bottom electrode and the case; it is connected with the alarm system and with power supply unit switch-off. Temperature sensors of the bottom electrodes are installed inside the base. Any explosion is impossible if metal leakage through the furnace bottom occurs [9, 3].

The furnace capacity makes it possible to feed charge materials by one load. If any additional loads are required, they can be added into the furnace when charge materials are already heated and sunk, but not into melt itself. The metal is poured out completely at the end of the melting. Under these conditions, any presence of water, ice etc. in charge materials will not result to melt slopping.

Suppression of local metal overheating [**10**]**.** The melting is started at high voltage and low arc current. Anode spot of the arc becomes attached to pieces of charge materials, melt drops flow down as soon as their weight is more than surface tension force. At the same time a melt is accumulated on the bottom, and any overheating is impossible. The melting is further running at higher current and voltage that is proportionally declined by power supply unit in the ratio of educed power in the arc and in its basic spot — 80–90 % and 20–10 % accordingly. The furnace bath is fed with significant amount of a melt; magneto-hydrodynamic mixing is applied to a melt under the arc spot. Further melting, melt heating, technological operations are performed with keeping the power thanks to the magneto-hydrodynamic mixing system. The ratio of energy given directly to a melt by the arc is 80–90 %, a cold metal runs under the arc at high speed and goes inside the melt. Any local melt overheating risk is eliminated.

Melt magneto-hydrodynamic mixing [**10**]. It is achieved thanks to the current spreading from basic spot of the arc to the bottom electrodes located at the periphery of the bath. At the same time, the interaction between horizontal and vertical components of the current with the current developed by electromagnetic field gives rise to toroidal mixing in a vertical section and rotating move in a horizontal section. The mixing is unstable and results to the generation of vortexes under a graphitized electrode and the bottom electrodes; with all this going on, the balance of melt stops moving. Special program to control the arc current and SCR converter keeps the mixing in constant form, adjusts its intensity, eliminates vortex flows above the bottom electrodes (**Fig. 12**).

Dust and gas emission suppression [**10**]**.** Magneto-hydrodynamic mixing and charge materials melting eliminates the local melting overheating, i.e. evaporation. The current stabilization by SCR converter and the above-described melting modes suppress the arc power variations. In accordance with $PV = nRT$ equation, for permanent furnace capacity, the gas pressure variations inside the furnace (giving rise to gas exchange with the environment) depend on the gas temperature variations. If electric mode is stable, the furnace gas temperature variations and oxygen penetration in the furnace are prevented. In this case, composition of furnace gases depends on melting products, mainly CO, C_nH_m, N_2 which are emitted out of the furnace at high concentration and high temperature. When interacting with oxygen in the air, the gas emissions ignite and burn up to completed oxides CO_2, H_2O. Practical absence of oxygen and high temperature of the furnace gases prevents metal oxidizing and forming of nitrogen oxides, cyanides, furans, other harmful elements, and intensive dilution of small amounts of furnace gases with a large amount of air, when entering the dust and gas removal system, and provides fquenching (quick cooling) of waste gases, preventing secondary generation of harmful compounds. Based on technological expedience, the furnace atmosphere can be replaced by nitrogen, argon, oxygen, other gases that are forcedly fed into the furnace, including the cases when they are fed through a hole in graphitized electrode at high temperature. Heat utilization of waste gases as well as cleaning of charge materi-

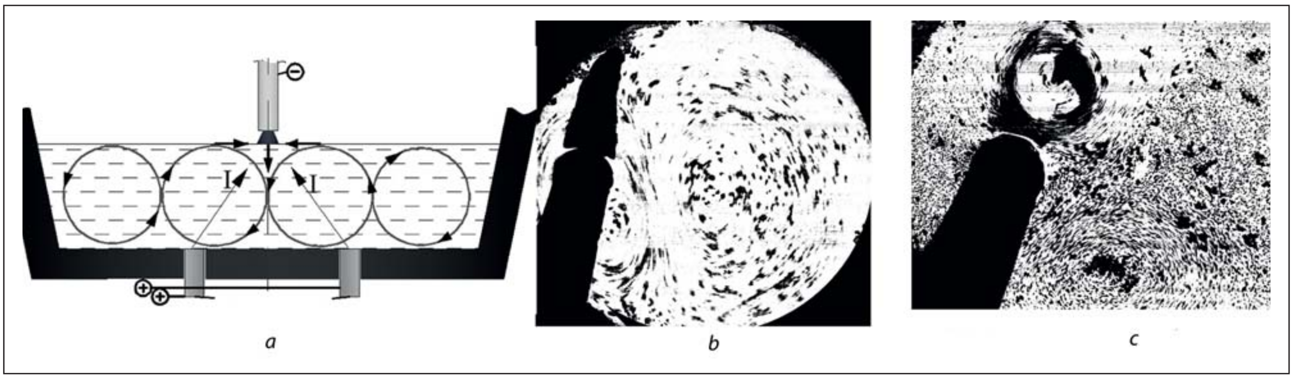

Fig. 12. Scheme of magneto-hydrodynamic mixing in GPDCAF-NG (Patent No. 2104450 "Electric melting method and arc furnace to make it performed"):
a — mixing of melt in its cross-section (bottom electrodes are shown below); *b* — mixing system is switched on, top view; *c* — mixing system is switched off, top view

als from organic and other contamination in the special units for of melting at GPDCAF-NG is not reasonable because the first operation takes less than 1 % from the input energy, while the second one is conducted in the best form during the melting process of charge materials.

Slag mode control. The main part of slag-forming additions is fed into a furnace together with charge materials. It allows to protect the metal from the furnace atmosphere during the whole melting process and to combine metal processing by slag with melting of charge material. Suppression of metal oxidizing in melting process prevents generation of initial slag, therefore composition and properties are preset by burdening and are changed under control. Other types of furnaces do not offer such possibilities. After metal melting, slag can be removed, for an example, for the purpose of steel dephosphorizing; at the same time new slag is formed 2–3 minutes after addition of slag-forming materials. The ratio characterizing relationship between metal temperature and slag can be changed by the arc modes. The magneto-hydrodynamic mixing allows to keep the effective "slag-melt" surface, to provide melt transportation to the area of slag interaction, keeping the homogeneity of the melt temperature and chemical composition. It allows to perform all ACAF technological operations – such as oxidazing-reducing and refining processes but much deeper and faster. For example, when ore kip occurs, decarburization speed of steel is 0,1% for three minutes, and steel carburization in producing of synthetic iron is combined with melting process. Possibilities of slag processes had an influence on the choice of construction type for GPDCAF-NG. As soon as slag keeps high refining ability until the end of the melting process, it is not expedient to cut it from a melt and to organize the bottom discharge, while it is reasonable to pour it out into a ladle when furnace is titled. The refining process is going on in the ladle when further melt is poured out. Advanced possibilities of GPDCAF-NG offer especially high effectiveness including possibility to produce high-quality metal after complete production process for steel, iron and other metals, i.e. ladle treatment is not required and eve harmful from the point of steel quality. At the same time ladle treatment of melt by argon, ammonia is not denied, as soon as vacuum treatment to obtain steel with any special properties or to remove copper. However, all these processes are characterized by low energy consumption can be performed thanks to the reserve of the melt temperature which losses during pouring into a ladle are very low due to homogeneity of the melt temperature in the furnace. Redistribution of energy flow during the melting from the arc and heat transfer from the arc to a melt made it possible to avoid usage slag foaming to decrease the heat losses and to keep slag activity at the same level thanks to lowering of its temperature along with wide use of water-cooled walls and roof.

As it was mentioned before, the GPDCAF-NG can provide effective production of aluminum alloys. This is resulted via elimination of local metal overheating during the melting which may give rise to the structure heredity deterioration. In melting of aluminum alloys, especially from secondary raw materials, some problems connected with high oxidability of metal surface, presence of non-metallic inclusions and solute hydrogen in charge materials can arise. High temperature gradient limited by small exceed of the melt temperature is formed on the surface of pieces of charge materials during melting. Under these conditions, hydrogen is actively emitted from metal, melt drops are filtered from non-metallic inclusions via passing through natural slag generated from charge materials. In aluminum recycling, these processes provide production of quality aluminum alloys with minimum loss and without preparation of charge materials and ladle treatment. Cost of aluminum recycling to obtain quality cast products in GPDCAF-NG are lowered by 5 and 15 times compared with induction melting and gas furnaces respectively [11].

Building the system for electric power supply. GPDCAF-NG is offered as a general-purpose unit for production of quality metals. Electric power is supplied from typical three-phases AC mains with voltage 6, 10, 35 kV and 0,38 kV — for small capacity furnaces. Practical absence of sharply variable loads and flicker allows to reduce the power reserve for dynamic stability of electric power supply equipment. This fact allows to increase the power of GPDCAF-NG electric supply system by 20–30 % during ACAF reconstruction or replacement; in this case it is not necessary to install filter compensation system, or to mount the most simple one.

The GPDCAF-NG electric power source consists of transformer with several three-phase secondary windings and the same number of sections of SCR converter with switches for consequent, parallel-consequent and parallel modes, smoothing reactors, heat exchanger to SCR cooling and control cabinet. This scheme allows to conduct the whole melting process at the same power, matching by switchings the current and voltage of electric power supply unit with the operating requirements of arc heating. In these conditions, a position high-speed circuit-breaker and voltage switching regulator are not mounted at transformer. The power supply units and furnace control boards include the overvoltage protection system, static and dynamic current protection, the system for managing and control of magneto-hydrodynamic mixing, the protection units for parasitic arc, bus bars fuse, and bottom electrodes [10,12], as well as the systems for arc current and voltage stabilization and control, automatic arc firing after fault, input energy melting control [10], water flow control, electric equipment status control. At present time, the works on development of the intelligence melting control system with self-adjustment of mode are being completed.

When choosing the capacity of electric power supply unit, its operation conditions at a customer site and features of power supply system should be taken into account. The minimum specific power of a furnace for iron and steel melting is 0,25–0,3 kVA/kg, while the maximum one is not limited. The melting time depends on the specific capacity and can last 25–30 minutes at S =1 kVA/kg and can reach 80–90 minutes at S = 0,25 kVA/kg. At the same time, the specific power consumption for melting changes slightly and is located within the range 410–450 kWt h/t but the cost of power supply equipment costs will rise significantly. Duration of technological melting period for steel including dephosphorizing, desulfurizing, carbonization, decarbonization, finishing of chemical composition, pure refining do not exceed 20 min and extra energy consumption is not more than 70–100 kWt·h/t but technological time and electric power consumption strongly depends on process managing (time for charging and additional charging, for slag discharge and feed of slag-forming additions, amount and time for conduction of chemical analysis, preparation of ferroalloys and their charging, as well as possibilities of charging and casting shop sections and organization of one-two-three shifts operation. When operation is perfectly organized, all this time can be decreased to 10–15 min; in such case it has no influence on the specific energy consumption. Therefore, it is expedient to force the melting by powerful electric power supply units with reaching melting time in the range of 60–70 min. Actually, without any changes in the steel-melting shop with ACAF, we have succeeded to cut off the specific energy consumption by 150 kWt·h/t as minimum and melting time by 1,5–2 times just by switching the furnace to the direct current; electric power supply system was not changed in that case.

Reliability. We had no claims for reliability of GPDCAF-NG operation from our customers. The product is granted with the European Certificate and produced by joint manufacturers having great national and foreign authority.

However, some customers have faced difficulties in maintenance of the bottom at starting period of mastering the equipment. For the case of normal operation and meeting all the instructions, the bottom with bottom electrodes operates much more reliable than ACAF bottom. The first melts required several simple patented procedures [13] to be done, in order to prevent loss of electric contact with charge materials, that can give rise to troubles at the beginning of melting, alarm switch-on and furnace switch-off due to overheating bottom electrodes. After bottom metallization during several meltings, there will be no need for special maintenance of bottom electrodes. If any breakdown of the bottom happens due to melt overheating, the bottom electrodes are subjected to “hot” or “cold” repair without replacement; such works are the same technologically as those for ACAF. The bottom service life in melting steels with ore kip and oxygen blowing is 1,5–3 years; in the case of melting of aluminum-based alloys it exceeds 10 years. During capital repair of the bottom with replacement of bottom electrodes, they are re-mounted in the bottom after repair. Reliability of mechanical parts of GPDCAF-NG and ACAF is the same for both furnaces. The service life of water-cooled cables and power supply unit elements is increased by many times thanks to a lack of dynamic loads.

Conclusions

It can be concluded from the experience of mastering of GPDCAF-NG that:

1. The furnaces have strong positions in Russian casting and foundry production.

2. The performance characteristics of the furnaces are mainly determined not by electric power consumption and possibility for accelerated melting, but by save of material resources, by possibility of production of high-quality metal from cheap regular charge materials, by decrease of cost of the capital funds due to elimination of additional, in particular, chemical types of energy and additional facilities, by use of refractory products mastered in Russia, by reduction of number of technological operations required for obtaining the high quality of finished products, by refusal from many harmful substances, by equipping the industry with technical facilities providing sharp reduction of harmful emissions (on the contraray to those enterprises who increased such emissions and environment protection expenses. The advantages of GPDCAF-NG in meeting these performance parameters are obvious.

3. Technologies and equipment of GPDCAF-NG are based not on the art, but on the most complete use of metallurgy theory, rich experience accumulated in production and operation of other types of furnaces, the results of technical progress in electrical engineering and other fields of technology and science.

4. The high performance characteristics of equipment are achieved not by switching the furnaces to DC arc heating, but by developing the conception of interconnected system and its use, as well as technical solutions developed and patented by EKTA during creation of GPDCAF-NG. Therefore, attempts to reduce furnace costs thanks to famous and more simple solutions make switching furnaces to DC senseless.

The intellectual property rights for our equipment and any relative processes are patent law protected.

More detailed information about DC arc furnaces to melt steels, irons, aluminum and cupper-based alloys can be asked from the NTF EKTA’s specialists at the following address: Russian Federation, Moscow, P.Romanova Street, Building 7, offices 410, 505. Tel: (495) 679-48-81, 679-48-43, or at www.stf-ecta.ru.

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High Nitrogen Steels with special functional properties

Production expansion of High Nitrogen Steels, both with low nickel content and without nickel, in various structural classes will be the main trend. Alloying steels with nitrogen is very promising to give then special functional properties for example corrosion resistance in bioactive environments, bactericidal activity or disinfecting ability, high resistance to special impacts, lightweight steels. Nitrogen is currently a quite normal alloying element together with C, Cr, Mn, Ni, *etc. It provides unique combination of strength, plasticity and corrosion resistance for steels. Industry uses a lot of nitrogen-alloyed steels of various structure classes — austenitic, ferrite, martensite and two-phased. In future these steels are quite possible to replace light and non-ferrous metals' alloys. Alloying steels with nitrogen is very promising to give then special functional properties for example corrosion resistance in bioactive environments, bactericidal activity or disinfecting ability, high resistance to special impacts, lightweight steels with lower density and high strength and plasticity.*

Key words: *high nitrogen Steels, steels for bioactive environments, biocidal steels, lightweight steels. nickel, corrosion resistance.*

1. Introduction

The significant application of nitrogen as an alloying element commenced in the 80s of the past century. The steels produced then, which contained 0.5–1.0% of nitrogen, were called High-Nitrogen Steels (HNS) or nitrogen "hyperequilibrium" steels. At such its contents, nitrogen imparts unique properties to the steel; for example, stainless high-nitrogen steels are characterized by high strength and high corrosion resis-