УДК 669.187:621.

**ANALYSIS OF FACTORS EFFECTING POWER CONSUMPTION & ARC EFFICIENCY IN ELECTRIC ARC FURNACES (EAF)**

**Singh Kapil Dev1 and Makarov Anatoliy Nikolaevich2,**

*1PhD. Scholar, Tver State Technical University, Tver, Russia.*

*2Prof. and Doctor of technical sciences, Tver State Technical University, Tver, Russia. E-mail:* [*tgtu\_kafedra\_ese@mail.ru*](mailto:tgtu_kafedra_ese@mail.ru)

# *Abstract*

*The analysis of factors like arc length and slag height in the entire range of electrical arc steel-making furnaces (EAF) from 0.5 to 120 ton was carried out to determine their influence on power consumption and arc efficiency in EAF. It was found that as the slag height increases, the arc efficiency increases to up to 70% to 80 % and power consumption decreases, whereas on the other hand when arc length at constant slag height increases to 1.42 times, the arc efficiency decreases to 30%, power consumption increases up to 25% to 30%, and thermal radiation fluxes increases to 1.3 -1.6 times.*

# Introduction

Russia is the 5th largest steel producing nation in the world, with 48 million tons of steel produced only in the year of 2019, with around 50 electrical arc steel-making furnaces (EAF) nationwide. With increasing global demand and competition a great emphasize is on increasing the efficiency of EAF and on cost effective steel production1. The slag layer and arc length in an EAF and their influence on the arc efficiency and electric power consumption in the entire range of steel making furnaces from 0.5t to 120t was studied.

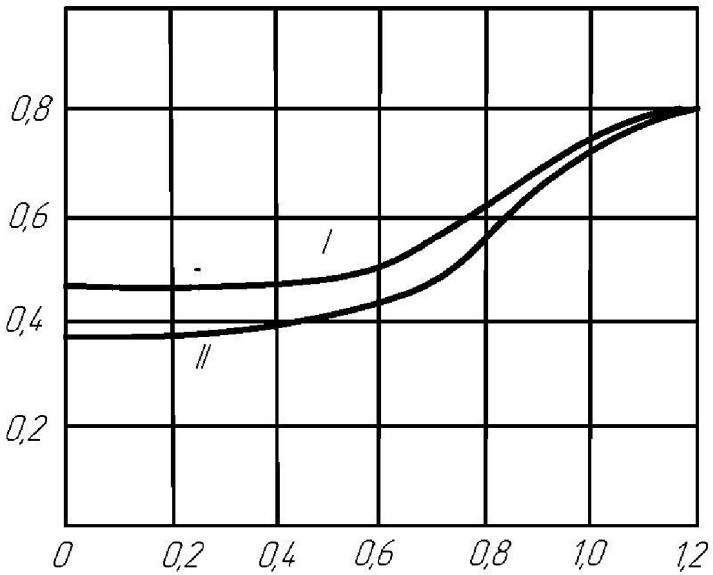
# Slag Height

The high power heavy duty electric arc steel making furnaces use coal powder injectors and oxygen for foaming, as a result slag height reaches 400-500 mm but in small capacity furnaces EAF-6, foaming devices are not used and slag height remains 40mm. We will further study how it influenced the efficiency of arcs and specific power consumption in furnaces.

# Effects of slag height on arc efficiency and specific power consumption in EAF.

In figure1, graph 1, describes the change in arc efficiency depending on the ratio of the arc length 𝐻𝐷/𝐻𝐿 in the EAF -100 furnace, whereas graph 2 shows the change in arc efficiency η=f(𝐻𝐷/𝐻𝐿) in the EAF-6 furnace, where devices are not used for foaming slag. As can be seen from figure1, graph 1, the arc efficiency increase unevenly with the height of the slag layer and the height of the arc depth into the slag in the EAF-100 furnace.

At an arc voltage of 280V and arc length of 325mm arc efficiency increased just by 8% from 0,45 to 0,49, as an increase in slag height from 0 to 195 mm was inefficient as 𝐻𝐷/𝐻𝐿 = 0.6, but with further increase in the height of the slag layer in the EAF - 100 furnace from 195 to 325 mm and 𝐻𝐷/𝐻𝐿=1.0, increased arc efficiency by 35% from 49 to 75 as specific power consumption decreased in EAF-100 to 385 kWh/t. The experimental studies were carried out on the EAF-120 of OJSC Ural steel10, which proved the outcomes of arc efficiency calculation. Studies proved that with increase in height of the slag layer from 238 to 356mm, specific power consumption decreased from 260-205 kWh/t as a result of decrease in heat losses of arcs, and increase in the efficiency of arcs due to increased shielding of arc radiation by slag10. As we know the parameters of arc for EAF-100 and EAF-120 are same, graph 1 in fig 1 was used to determine the efficiency of arcs of the EAF=120 furnace of OJSC Ural steel and it was found that with an increase in the height of the slag layer from 278 to 356mm, the arc efficiency increased from 0,55 to 0,77 i.e. by 29% and the specific power consumption decreased from 260 to 205 kWh/t by 22%.



**Figure 1.** The dependence of the arc efficiency of the EAF-100 (I) and EAF-6 (II) furnaces on the penetration of the arcs into the metal bath and slag.

Analyzing graph 2, it was found that, as the distance from arcs to the wall is 0.69m or 3 times less compared to EAF-100, it effects arc efficiency which is η=0.35 for EAF-6 which is 24% less compared to EAF-100, as slag foaming devices are absent in EAF-6 and as a result of which it has slag height of 35mm to 40mm, long operating time and low arc efficiency results in specific power consumption increment in EAF-6 to 475kWh/t for melting the charge and upto 750 kWh/t for overall melting. Use of slag foaming devices in EAF-6 furnace can increase the arc efficiency in by 15% to η=0.67 and decrease the specific power consumption to 11% to 15% but while considering use of such devices we need to keep in mind the factors like investment in gas cleaning, the furnace downtime, effect of oxygen and carbon containing material injection on the increase in the waste of expensive alloying elements (chromium, molybedrium, vanadium etc) on the quality of the finished metal.

# Arc length

Another important factor affecting energy consumption and efficiency in an EAF is arc length. At present, EAF-100 furnaces operate on both long and short arcs, and there is ongoing discussion about the advantages and disadvantages of working with long and short arcs. To determine better arc length, it is necessary to calculate and analyze the distribution of arcs over the surface of the walls of a 100 ton furnace. When changing the length of the arcs, it is necessary to find out the effect of the length of the arcs on the efficiency of arcs and the specific power consumption in arc EAF.

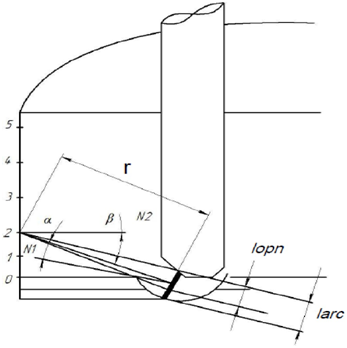
# Effects of arc length on arc efficiency and specific power consumption

A very important factor while determining effect of arc length on arc efficiency and specific power consumption is to calculate the densities of the thermal radiation fluxes of the arcs along the height and perimeter of the walls of a 100 ton EAF at various length of arc at constant power. Figure 2 shows the necessary construction for calculation in AutoCAD & Excel program.

The density of the thermal radiation flux of the arc q falling on the design site located on the walls of the EAF was determined by the expression [1]:

q = (1)

where is the proportion of arc power released in the arc column, determined by the method described in [1]; is the arc power, kW; k is the absorption coefficient of the furnace gas atmosphere, varies in the EAF from 0.1 to 1.3 [1], we take the average absorption coefficient K=0.7 [1].



**Figure. 2**. Diagram for calculating the fluxes of thermal radiation of arcs on the walls of EAF.

The symbols used in figure 2 are as follows:

0...5 – the calculated points on the walls of furnaces; – arc length, m;

– is the length of the open part of the arc radiating heat flux on the calculated area, m;

r – ray, the distance from the arc to the calculated points on the walls, m;

α – angle between the ray r from the middle of the open part of the arc and the perpendicular N1 to the axis of the arc, held at the beginning of the ray r on the arc, grad.;

β – the angle between the normal N2 to the surface of the walls to the calculated point and ray r, grad..

The results of calculating thermal radiation fluxes showed that when furnace operates at short length = 300mm and long = 425mm respectively, and when the arc length is increased from

300 to 425 mm in radiant furnace atmosphere the maximum flux densities of thermal radiation from the arcs increase from 600 to 650 kW in the lower part of the walls at 70mm. Densities of heat fluxes of radiation on sections of walls located opposite and between the arcs was found that long arc's 425mm is 15% -30% more in comparison with density of heat fluxes of radiation on the walls of short arc’s 300mm. The higher density of thermal radiation from long arcs 𝑙𝑎𝑟𝑐= 450 mm on the walls of the EAF-100 furnace is associated with the higher open, not buried in the slag, height of the arcs, and the lower efficiency of the arcs. For long arcs = 450 at / = 300/450 = 0.67, efficiency of arcs η = 0.52. For short arcs = 300 at /= 300/300 = 1.0, efficiency of arcs η = 0.74.

Thus, with an increase in the arc length from 300 to 450 mm, the density of heat radiation fluxes of three arcs along the height and perimeter of the walls of the EAF-100 furnace increases by 15 - 30%, the heat losses by radiation of arcs increases by 30% into the surrounding space, on the walls, vault, absorbed by the dust and gas atmosphere of the furnace as a result the efficiency of the arcs decreases by 30%. When comparing the energy consumption for the production of 1 ton of high-quality high-alloy steel in electric arc steel- making furnaces with short arcs and new EAF with long arcs when melting ordinary and reinforcing steel, it was found that the energy consumption in new EAF with long arcs is 100 kWh / t higher compared to with short arcs [19].

# Conclusion

With an increase in the height of the slag layer, the efficiency of the arcs increases and the power consumption and the density of heat fluxes on the walls decreases. With an increase in the length of the arc, the efficiency of the arc decreases and the consumption of electricity and the flux of thermal radiation of the arcs and on the walls increases. Thus, it is possible to increase the efficiency of the arc and reduce the specific power consumption with an increase in the height of the slag layer, and regulation of the arc length and flows of thermal radiation of the arc to the walls.

# References

1. Makarov AN 2014 Heat exchange in electric arc and flare metallurgical furnaces and power plants (St. Petersburg: Lan) 384
2. Evstratov VG, Kiselev AD, Zinurov I Yu 2012 Features of the thermal operation of the EAF - 120 Consteel electric furnace at the Ashinskiy metallurgical plant Electrometallurgy 8 2–6
3. Nikolsky LE, Smolyarenko VD, Kuznetsov LN Thermal operation of arc steel-making furnaces (Moscow: Metallurgy) 344
4. Okorokov NV 1971 Electric arc furnaces (Moscow: Metallurgy) 347
5. Egorov AV 1985 Electric melting furnaces of ferrous metallurgy (Moscow: Metallurgy)

280

1. Soifer VM 2009 Steel smelting in acid electric furnaces (Moscow: Mechanical Engineering) 480
2. Samokhvalov GV, Chernyi GI 1984 Electric furnaces of ferrous metallurgy (Moscow:

Metallurgy) 232

1. Leskov GI Electric welding arc (Moscow: Mashinostroenie) 335
2. Tikhodeev GM 1961 Energy properties of an electric welding arc (Moscow: Publishing house of the Academy of Sciences of the USSR) 236
3. Kuznetsov MS, Yakushev EV, Kulagin SA 2010 Influence of the charge weight and slag thickness on the technology of steelmaking in an arc furnace Electrometallurgy 2 2 - 6
4. Nefedov AV, Nefedova EV 2015 Import-substituting technology for unloading dust from bunkers of the electric steel-making shop at OJSC Ural Steel 12 74 - 76
5. Simonyan LM, Khilko AA, Lysenko AA et al. 2010 Electric steelmaking dust as a dispersed system Izvestiya vuzov. Ferrous metallurgy 11 68 - 75
6. Gudim Yu A, Ovchinnikov ST, Zinurov I Yu 2010 Metal losses during steel smelting in arc furnaces and ways to reduce them Electrometallurgy 6 11 - 15.
7. Makarov AN Calculation and analysis of the relationship between efficiency and location of arcs with power consumption in arc furnaces of small and large capacity arc melting furnaces. Part I. Calculation and analysis of the relationship between arc efficiency and power consumption 2019 Metallurg 4 29 - 35
8. Makarov AN Calculation and analysis of the relationship between efficiency and location of arcs with power consumption in small and large capacity arc melting furnaces. Part II. Calculation and analysis of the relationship between the location of arcs, walls and power consumption 2019 Metallurg 5 21 - 27
9. Kuzmin M. G, Cherednichenko VS, Bikeev RA et al. 2014 Water-cooled units of heavy- duty steel-making furnaces Electrometallurgy 7 8 - 16
10. Humer O 1997 Water-cooled panels of modern heavy-duty arc furnaces MRI Metallurgical plants and technologies 8 6 - 14
11. Kuzmenko AG, Frolov Yu F, Pozdnyakov MA et al. 2011 Electric arc furnaces: state, problems Electrometallurgy 3 2 - 7
12. Kuzmenko AG, Frolov Yu F, Pozdnyakov MA et al. 2012 Prospects for the development of an electric steel-making complex - electric furnaces and ladle furnaces for steel production
13. Electrometallurgy 11 2 – 11

**АНАЛИЗ ФАКТОРОВ, ВЛИЯЮЩИХ НА ПОТРЕБЛЕНИЕ ЭЛЕКТРОПИТАНИЯ И ДУГОВЫЙ ЭФФЕКТИВНОСТЬ В ДУГОВЫХ ПЕЧИ (ДСП)**

**Сингх Капил Дев1 и Макаров Анатолий Николаевич2,**

***1****Аспирант, Тверской государственный технический университет, Тверь, Россия.*

*2Проф. и доктор технических наук, Тверской государственный технический университет, г. Тверь, Россия. Электронная почта: tgtu\_kafedra\_ese@mail.ru*

*Анализ таких факторов, как длина дуги и высота шлака во всем диапазоне электродуговых сталеплавильных печей (ДСП) от 0,5 до 120 тонн, был проведен для определения их влияния на потребляемую мощность и КПД дуги в ДСП. Было обнаружено, что с увеличением высоты шлака КПД дуги увеличивается до 70-80%, а потребление энергии снижается, тогда как, с другой стороны, когда длина дуги при постоянной высоте шлака увеличивается до 1,42 раза, КПД дуги снижается до 30 %, энергопотребление увеличивается до 25% - 30%, а потоки теплового излучения увеличиваются в 1,3 - 1,6 раза.*

Список литературы

[1] Макаров А.Н. 2014 Теплообмен в дуговых и факельных металлургических печах и электростанциях (Санкт-Петербург: Лань) 384

[2] Евстратов В.Г., Киселев А.Д., Зинуров И.Ю. 2012 Особенности термической работы электропечи ДСП - 120 Consteel на Ашинском металлургическом заводе Электрометаллургия 8 2–6

[3] Никольский Л.Е., Смоляренко В.Д., Кузнецов Л.Н. Термический режим электродуговых сталеплавильных печей (М .: Металлургия) 344

[4] Окороков Н.В. Электродуговые печи 1971 (М .: Металлургия) 347

[5] Егоров А.В. 1985 Электроплавильные печи черной металлургии (М .: Металлургия).

280

[6] Сойфер В.М. 2009 Выплавка стали в кислых электропечах (М .: Машиностроение) 480

[7] Самохвалов Г.В., Черный Г.И. 1984 Электропечи черной металлургии (Москва:

Металлургия) 232

[8] Лесков Г.И. Электросварочная дуга (М .: Машиностроение) 335.

[9] Тиходеев Г.М. 1961 Энергетические свойства электросварочной дуги (М .: Изд-во АН СССР) 236.

[10] Кузнецов М.С., Якушев Е.В., Кулагин С.А. 2010 Влияние массы шихты и толщины шлака на технологию выплавки стали в дуговой печи Электрометаллургия 2 2 - 6

[11] Нефедов А.В., Нефедова Е.В. 2015 Импортозамещающая технология выгрузки пыли из бункеров электросталеплавильного цеха ОАО «Уральская Сталь» 12 74 - 76

[12] Симонян Л.М., Хилько А.А., Лысенко А.А. и др. 2010 Электросталеплавильная пыль как дисперсная система Известия вузов. Черная металлургия 11 68 - 75

[13] Гудим Ю.А., Овчинников С.Т., Зинуров И.Ю. 2010 Потери металла при выплавке стали в дуговых печах и пути их снижения Электрометаллургия 6 11 - 15.

[14] Макаров А.Н. Расчет и анализ взаимосвязи КПД и расположения дуги с потребляемой мощностью в дуговых печах малой и большой мощности дугоплавильных печей. Часть I. Расчет и анализ зависимости КПД дуги от энергопотребления 2019 Металлург 4 29 - 35

[15] Макаров А.Н. Расчет и анализ взаимосвязи КПД и расположения дуги с потребляемой мощностью в дуговых плавильных печах малой и большой мощности. Часть II. Расчет и анализ взаимосвязи расположения дуг, стен и энергопотребления 2019 Металлург 5 21 - 27

[16] Кузьмин М.Г., Чередниченко В.С., Бикеев Р.А. и др. 2014 Водоохлаждаемые агрегаты тяжелых сталеплавильных печей Электрометаллургия 7 8 - 16

[17] Humer O 1997 Водоохлаждаемые панели современных сверхмощных дуговых печей MRI Металлургические заводы и технологии 8 6 - 14

[18] Кузьменко А.Г., Фролов Ю.Ф., Поздняков М.А. и др. 2011 Электродуговые печи: состояние, проблемы Электрометаллургия 3 2 - 7

[19] Кузьменко А.Г., Фролов Ю.Ф., Поздняков М.А. и др. 2012 Перспективы развития электросталеплавильного комплекса - электропечи и печи-ковши для производства стали Электрометаллургия 11 2 - 11

**Сингх Капил Дев**, аспирант ФГБОУ ВО «ТвГТУ», г. Тверь, Россия. E-mail: kapil92singhdev@gmail.com

**Макаров Анатолий Николаевич,** д-р техн. наук., профессор, заведующий кафедрой «Электроснабжения и электротехники» ФГБОУ ВО «ТвГТУ», г. Тверь, Россия. E-mail: tgtu\_kafedra\_ese@mail.ru