DOI: https://doi.org/10.36719/2789-6919/57/174-179

Shukur Nasirov
Azerbaijan State Oil and Industry University
PhD in Technical Sciences
https://orcid.org/0000-0001-6421-7549
shukur.nasirov@asoiu.edu.az
Jamala Mammadova
Azerbaijan State Oil and Industry University
PhD in Technical Sciences
https://orcid.org/0000-0001-5147-2233
cemile_adna@mail.ru

Research on the Development Directions of a High-parameter energy blocks

Abstract

The article examines scientific and technical approaches to improving the energy efficiency of steam-turbine thermal power plants (TPPs), which play a dominant role in modern electric power engineering. It is noted that approximately 65% of global electricity generation and nearly 90% of electricity production in Azerbaijan are provided by thermal power plants, making the efficient use of fuel and energy resources and the reduction of environmental impact critical objectives. Although the main technological equipment of steam-turbine units has reached a high level of technical maturity, the principal potential for further improvement of technical and economic performance lies in increasing the initial steam parameters, specifically pressure and temperature.

The study analyzes the development stages of power units operating under supercritical and ultra-supercritical steam parameters, as well as their thermodynamic advantages and operational performance indicators. The results demonstrate that higher steam parameters increase turbine heat drop and output power, improve the efficiency of both the power unit and the plant as a whole, and reduce specific fuel consumption. Increased efficiency also leads to a significant reduction in emissions of CO_2, NO_x, SO_x, and other harmful pollutants.

Furthermore, the article investigates the mechanical strength, heat resistance, and long-term operational characteristics of modern ferritic and martensitic steels P91 and P92 used in ultra-supercritical technologies. Although the application of advanced materials increases capital costs, these expenses are recovered within approximately 3-4 years through fuel savings and improved energy efficiency.

Keywords: *Steam-gas plant, heating scheme, operating mode, critical, supercritical, gas turbine, steam turbine, waste heat boiler, power unit, efficiency*

Şükür Nəsirov
Azərbaycan Dövlət Neft və Sənaye Universiteti
texnika üzrə fəlsəfə doktoru
https://orcid.org/0000-0001-6421-7549
shukur.nasirov@asoiu.edu.az
Cəmalə Məmmədova
Azərbaycan Dövlət Neft və Sənaye Universiteti
texnika üzrə fəlsəfə doktoru
https://orcid.org/0000-0001-5147-2233
cemile_adna@mail.ru

Yüksək parametrli energetik blokların inkişaf istiqamətlərinin tədqiqi

Xülasə

Məqalədə müasir elektroenergetikada buxar-turbinli istilik elektrik stansiyalarının (İES) aparıcı rol oynaması şəraitində onların energetik səmərəliliyinin artırılmasının elmi-texniki yanaşmaları araşdırılmışdır. Qeyd olunur ki, dünya üzrə elektrik enerjisi istehsalının təqribən 65%-i, Azərbaycanda isə elektrik enerjisi istehsalının təxminən 90%-i istilik elektrik stansiyalarının payına düşür ki, bu da yanacaq-enerji resurslarından səmərəli istifadənin təmin edilməsini və ətraf mühitə təsirin azaldılmasını mühüm və aktual vəzifəyə çevirir. Buxar-turbin qurğularında istifadə olunan əsas texnoloji avadanlıqlar yüksək texniki yetkinlik səviyyəsinə çatmış olsa da, texniki-iqtisadi göstəricilərin daha da yaxşılaşdırılması üçün əsas ehtiyat mənbəyinin buxarın başlanğıc parametrlərinin, yəni təzyiqinin və temperaturunun artırılması olduğu əsaslandırılır.

Tədqiqatda superkritik və ultrasuperkritik buxar parametrləri ilə işləyən enerji bloklarının inkişaf mərhələləri, onların termodinamik üstünlükləri və istismar göstəriciləri təhlil edilmişdir. Alınan nəticələr göstərir ki, buxarın yüksəldilmiş parametrləri turbində istilik düşküsünün və çıxış gücünün artmasına, enerji blokunun və bütövlükdə stansiyanın faydalı iş əmsalının yüksəlməsinə, həmçinin, yanacağın xüsusi sərfinin azalmasına səbəb olur. Faydalı iş əmsalının artması atmosferə atılan CO_2, NOx, SOx və digər zərərli tullantıların əhəmiyyətli dərəcədə azalmasına da şərait yaradır.

Bundan əlavə, məqalədə ultrasuperkritik texnologiyalarda tətbiq olunan müasir ferrit və martensit sinifli P91 və P92 poladlarının mexaniki möhkəmliyi, istiliyədavamlılığı və uzunmüddətli istismar xüsusiyyətləri araşdırılmışdır. Qeyd olunur ki, qabaqcıl materiallardan istifadə kapital xərclərinin artmasına səbəb olsa da, yanacağa qənaət və energetik səmərəliliyin yüksəldilməsi hesabına bu xərclər təxminən 3–4 il ərzində ödənilir.

***Açar sözlər**: buxar-qaz qurğusu, istilik sxemi, iş rejimi, kritik, superkritik, qaz turbini, buxar turbini, utilizasiya qazan, enerji bloku, səmərəlilik*

Introduction

Currently, electric power is mainly produced in steam turbine thermal power plants operating on natural fuels. 65% of the electric power produced worldwide, and 90% in Azerbaijan, is manufactured in thermal power plants. Therefore, increasing the energy efficiency of steam turbine plants is one of the urgent issues. The equipment used in steam turbine power plants has been improved to a high level. Increasing the technical and economic indicators of such plants can be achieved by increasing the initial parameters of steam. The change in steam parameters over the years in steam turbine power plants is shown in Figure 1. (Abdullayev et al., 2013; Abzərli & Arifli, 2020; Kəlbəliyev et al., 2011; Dorokhov & Sedlov, 2007).

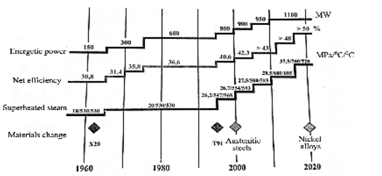

Figure. 1. Changes in parameters in steam-powered power plants

The figure shows that during the years 2000-2015, power units operating with supercritical parameters of steam were actively developed, and currently this s of transition of steam to ultra supercritical parameters. As a result of long-term work to increase the efficiency of the steam turbine – that is, research on increasing the pressure and temperature of superheated steam, the temperature of steam reheating - power units operating with super technology has been fully studied and is being used. In this case, the efficiency reached 50%, the temperature- t_0=700^{0}C, and the pressure 32-35 MPa. Currently, leading countries are solving the issue critical (P_0=31-32 MPa, t_0=560-600^{0}C), ultra supercritical (P_0=37-38 MPa, t_0=700^{0}C) parameters were created. Currently, supercritical units are being replaced by power units operating with the technology of ultra-supercritical units. Due to the increase in energy efficiency in such units, fuel consumption is reduced. At the same time, environmental pollutants are also reduced. Thus, when the efficiency increases by 1%, CO_2, NOx, SOx compounds and solid particles decrease by about 2%.

With the transition of gas-fired power plants to a steam-gas turbine with combined cycle, it has been possible to increase the efficiency to 60% by increasing the temperature of the combustion heat supplied to the gas turbine to 1200-1500^{0}C (Favorskiy et al., 2004; Kehlhofer et al.,1997; Olxovskiy, 2013; Truxnıy, 2013) but this has not yet been possible in power plants powered by other fuels. One of the solutions to this problem is to increase the parameters (pressure and temperature) of the steam. When the parameters of the steam entering the turbine increase, the heat loss in the turbine, power, the efficiency of the turbine, the block and the thermal power plant increase, and the specific fuel consumption decreases. As a result, fuel is saved, the amount of flue gases emitted into the atmosphere reduces, and the environmental load decreases (Figure 2).

It should be noted that despite the increase in trends in the development of non-traditional technologies in electricity generation, natural fuels are mainly used in the world's electric power generation, and their number is also increasing. 60% of gas and solid fuels are used in electric power generation. Combined cycle power plants with steam-gas units operate on the Brayton-Rankin cycle. In order to reduce the amount of carbon dioxide emitted into the atmosphere, power engineers are required to increase the thermodynamic efficiency of the energy complex. Conducting scientific research in this area is one of the urgent issues.

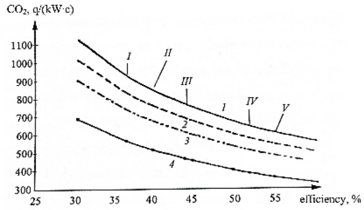

Figure. 2. Dependence of CO_2 emissions on net efficiency

1 – when burning coal; 2, 3 – when burning biomass with coal;
4 – when burning natural gas

I – average value for modern operating thermal power plants; II – average value for EU countries; III – average value for thermal power plants operating with parameters higher than critical in Denmark; IV – thermal power plant project AD700; V – latest thermal power plant projects

Research

When the initial temperature of the working medium of the best combined steam-gas plant is 1500^{0}C, the efficiency is 60% (Truxnıy, 2013; Tsanev et al., 2011). In this regard, the improvement of technologies in steam-gas plants is one of the main issues. Certain progress has been made in the field of using solid fuels in combined steam-gas plants. In this case, the internal coal gasification is applied in a complex cycle, that is, artificial gases are obtained from solid fuels and the obtained artificial gases are fed to the combustion chamber of the gas turbine (Kruglikov et al., 2012; Truxnıy, 2013; Məmmədova, 2019; Nəsirov & Neymətov, 2025; Nəsirov et al., 2026; Neymətov & Nəsirov, 2025). In this case, the efficiency of the steam-gas plant decreases, net efficiency compared to a steam-gas plant using natural gas is 41-45% (Usova, 2011; Zısin, 2010). It should be noted that steam-gas plants operating with internal coal gasification are very expensive, it is 4000 dollars/kWh (1010. Cost and performance data, for power generator technologies, 2012).

Therefore, it is more convenient to use steam turbine units operating on coal and with increased parameters. In Europe, China, Japan, and America, power units operating with supercritical parameters (P_0=32 MPa, t_0=600-620^{0}C) are operated, and the efficiency of such plants is 44%. In order to increase technical and economic indicators, power units operating with higher ultra supercritical parameters (P_0=34-36 MPa, t_0=700-760^{0}C) are actively developed in the mentioned countries. For the creation of ultracritical and ultra supercritical units, programs are developed by scientific research institutions, manufacturers of power equipment, and operating companies, and the implementation of the programs is monitored.

Main promising issues to be solved.

1. Development of modern high-efficiency, environmentally friendly technologies.
2. Creation of a new generation power equipment manufacturing industry.
3. Decommissioning of thermal power plants with low economic indicators and replacing them with promising, highly efficient thermal power plants that require low costs for the production of electricity and heat.
4. Reduction of specific fuel consumption and staffing factor of the equipment remaining in operation.
5. Reduction of waste discharged into the environment.
6. Reduction of repair costs.

In Russia, the introduction of promising coal-fired units operating with supercritical and ultra supercritical parameters is also prognosed and research is being carried out. Since 2021, the implementation of these studies and the creation of new, highly efficient units with an efficiency of 50% for electric power generation has begun (Truxnıy, 2013; Tsanev et al., 2011; Tumanovskiy, 2017). Currently, other countries are also addressing the issue of transition to power plants operating with ultra supercritical parameters. Another issue is the use of heat-resistant, expensive materials in equipment due to the increase in steam parameters and the increase in capital costs of power plants in this case.

Calculations show that the capital costs of the plant may increase by 35-40% due to the improvement of the boiler plant, turbine and auxiliary equipment (Truxnıy, 2013; Tsanev et al., 2011; Tumanovskiy, 2017). When manufacturing such blocks, high-strength steels of the ferritic and ferritic martensitic class are used.

The thick-walled outlet manifold, main steam pipe and intermediate heater pipelines are made of a new grade austenitic steel P 91. This steel contains 9% chromium. Another austenitic steel is made of P 92, which contains 11% chromium. The creep limit of martensitic steels is shown in Figure 3.

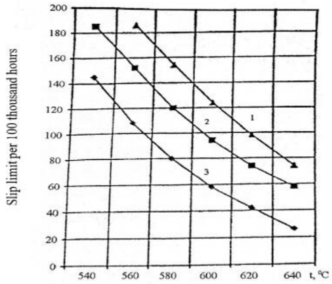

Figure 3. The limit of steel creep depending on temperature

1 – P - 92; 2 - P - 91; 3 – X 20

The graph shows that the slip limit of P 92 steel is 2 times higher than that of X 20 steel. X 20 steel has long been used in the mechanical engineering industry. When using P 91 and P 92 steels, the wall thickness is taken less and the slip limit is also higher, and their value is not higher than the value of the previous steels. In addition, assembly work has shown that P 91 and P 92 steels are welded faster than X 20, which contains 12% chromium. Due to the use of expensive metals in the mentioned stations, capital costs increase by 30%. However, this is paid off within 3-4 years.

Now let's compare the thermal efficiency of plants operating with parameters higher than critical and supercritical. As it is mentioned, thermal power plants operating on organic fuels dominate in the energy system. The creation of TPPs (thermal power plants) with powerful energy blocks is carried out in two directions - the creation of steam power plants operating on liquid, gas, solid fuels and the creation of steam-gas plants operating on gaseous fuels. The main goal is to reduce the amount of fuel consumed. However, in this case, when creating two different types of power plants, it is necessary to take into account that they have various technical advantages. The degree of improvement of the steam-gas plant is higher than that of the steam-power plant.

In this regard, it is more expedient to create promising ecological thermal power plants equal to the thermal efficiency of the steam-gas plant. Despite the 30% difference in capital investment between power units operating with critical parameters ($P_0 = 24{,}5\ MPa,\ t_0 = 338^0C, t''_{ih} = 552^0C$) and power units operating with supercritical parameters ($P_0 = 34{,}1\ MPa,\ t_0 = 650^0C$, $t''_{ih} = 693^0C$), power plants operating with increased parameters are economically advantageous. For this purpose, a comparison of the thermal efficiency of power plants operating with critical pressure and supercritical pressure was carried out. The creation of powerful 300-400 MW power units in accordance with modern brands of austenitic steels is a reality. In such units, the steam pressure in front of the turbine is P_0=31-32 MPa, the temperature $t_0 = 625 - 630^0C$, the feed water temperature is 310^{0}C, the pressure before the first intermediate heating is 7 MPa, the temperature is 565^{0}C, the steam pressure after the second intermediate heating is 2.0-2.5 MPa, the temperature is 565^{0}C. In this case, the change in specific fuel consumption is shown in the table below.

It can be seen from the table that the specific fuel consumption decreases by 7%. When comparing the power unit with a pressure of 31 MPa, a temperature of 600/560/566^{0}C, and a feed water temperature $t_{fw} = 275^0C$, with the base standard unit, there is a saving of 14.8 g/kWh of conventional fuel.

Table 1.
Impact of factors reducing specific fuel consumption on reducing specific fuel consumption, in %

Factors that reduce specific fuel consumption	Reduction in specific fuel consumption, in %
Increase in fresh steam pressure P_0=26.5 MPa to 31 Mpa	2,1
Increasing the temperature of the fresh steam from 540^{0}C to 630^{0}C	2,4
Steam temperature increases in the first stage reheating	0,8
Steam temperature increases in the second stage reheating	1,8
Raising the feed water temperature from 270^{0}C to 310^{0}C	0,8

If to assume a favorable feed water temperature $t_{fw} = 310 - 315^0C$ and take the temperature of fresh steam $t_0 = 630^0C$, the additional relative increase in fuel will be up to 2%. In units operating with supercritical parameters, it is planned to bring the temperature to 600-630^{0}C (Table 1). The operation of supercritical and supercritical units is generally positive. The availability factor of all units is on average 90 - 94%. Transition to critical parameters of steam does not affect the availability factor of the equipment.

Conclusions

1. The advantages and prospects of units operating with supercritical and ultra supercritical parameters have been studied.
2. To increase the efficiency of power plants, it is more expedient to operate them at water parameters higher than critical ones.

3. Due to the use of expensive metals in such units, capital costs increase by 30%, but this is repaid in 3-4 years.

4. By transition to the supercritical parameter, the useful efficiency of the plant increases from 41% to 50% and the specific fuel consumption decreases by 7%, saving fuel, reducing the amount of harmful gases emitted into the atmosphere, and reducing the environmental burden.

References

1. Abdullayev, K.M., Kəlbəliyev, F.İ., Məmmədova, C.P., Nəsirov, Ş.N. (2013). *İstilik elektrik stansiyasının buxar və qaz turbinləri.* Zaman–3.
2. Abzərli, M.M., Arifli, K.S. (2020). *Kombinə tsiklli elektrik stansiyalar.* Dərs vəsaiti. Elm.
3. *Britannica* – Gas turbine engine. (n.d.). https://www.britannica.com/technology/gas-turbine-engine
4. Dorokhov, E.V., Sedlov, A.S. (2007). *Proyektirovaniye teplovoy skhemy energoblokom TES na superkriticheskikh parametrakh: uchebnoye posobiye.* İzdatel’skiy dom MEI.
5. Favorskiy, O.N. (2017). Aktual’nyye problemy obespecheniya energetiki strany konkurentosposobnym oborudovaniyem. *Vestnik Rossiyskoy akademii nauk, 8*, 619–688.
6. *GE Power* – Gas turbines. (n.d.). https://www.ge.com/power/gas/gas-turbines
7. Kanaev, A.A., Korneev, M.İ. (2004). *Parogazovıye ustanovkı.* Maşınostroyeniye.
8. Kəlbəliyev, F.İ., Məmmədova, C.P., Nəsirov, Ş.N. (2011). *İstilik elektrik stansiyaları.* Zaman–3.
9. Kehlhofer, R., Hannemann, F. et al. (1997). *Combined Cycle Gas and Steam Turbine Power Plants.* 3rd ed., Penn Well Publishing Company.
10. Kondratyev, A.A., Rassoxin, V.A., Oleynikov, S.Yu., Kondratyeva, E.A., Osipov A.V. (2017). Razvitiye parovykh turbin na sverkhkriticheskiye i super-sverkhkriticheskiye parametry para. *Vestnik Bryanskogo gosudarstvennogo tekhnicheskogo universiteta, 1*(54), 72–82.
11. Kruglikov, P.A. və b. (2012). Vybor printsipial’nykh skhemnykh resheniy ugol’nogo energobloka na superkriticheskiye parametry para. *Teploenergetika, 9*, 9–16.
12. Məmmədova, C.P. (2019). *Buxar və buxar-qaz turbinli istilik elektrik stansiyalarının istilik sxemlərinin hesablama metodları.* ADNSU nəşriyyatı.
13. Nəsirov, Ş., Neymətov, S. (2025). “ŞİMAL-1” buxar-qaz qurğusu kondensatorunun iş rejiminin analizi. *Elmi İş. Beynəlxalq Elmi Jurnal*, *19*(12), 184–190.
14. Nəsirov, Ş., Əliyeva, A., Həşimov, S. (2026). Buxar-qaz qurğularının istilik sxeminin və iş rejiminin analizi. *Elmi İş. Beynəlxalq Elmi Jurnal, 20*(1), 170–184.
15. Neymətov, S., Nəsirov, Ş. (2025). Buxar qaz qurğusunun sxeminin analizi. *Azərbaycan Ali Texniki Məktəblərinin Xəbərləri, 50*(06), 213–222.
16. Olxovskiy, G.G. (2013). Perspektivnıye gazoturbinnıye i parogazovıye ustanovkı dlya energetiki (obzor). *Teploenergetika, 2*, 3–12.
17. *Power Magazine* – History of Power: The Evolution of the Electric Generation Industry. (n.d.). https://www.powermag.com/history-of-power-the-evolution-of-the-electric-generation-industry/
18. Truxnıy, A.D. (2013). *Parogazovıye ustanovkı elektrostantsıy.* İzdatelskiy dom MEİ.
19. Tsanev, S.V., Burov, V.D., Remezov, A.E. (2011). *Gazoturbinnıye energetıçeskiye ustanovkı.* İzdatelskiy dom MEİ.
20. Tumanovskiy, A.G. (2017). Perspektivy razvitiya ugol’nykh TES Rossii. *Teploenergetika, 6*, 3–13.
21. Usova, G.İ. (2011). Analiz raboty osvoyennykh PGU na tverdom toplive. *Energosbe-regayushchiye tekhnologii, 1*, 257–260.
22. Zısin, L.V. (2010). *Parogazovıye i gazoturbinnıye ustanovkı.* Politeh.

Received: 08.01.2026
Approved: 14.04.2026