ISSN 2522-9818 (print) *Innovative technologies and scientific solutions for industries. 2017. No. 2 (2)*

UDC 338.984

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ECONOMIC EFFICIENCY OF MODERNIZING THE EQUIPMENT FOR THERMAL POWER PLANTS

The **subject** matter of the study is the economic efficiency of modernizing equipment for thermal power plants (TPP). The **goal** of the study is to identify the economic efficiency of modernizing the equipment of the TPP basing on new technology and taking into account cost minimization and environmental requirements. The **subject** of the study is the theoretical and practical aspects of the economic efficiency of equipment modernization. To find a solution of this problem, the feasibility analysis was used to determine the current state of TPP equipment and the indicators of the parameters of old and new equipment as well as to introduce new equipment, which enables burning low-grade and waste coal in a circulating fluidized bed (CFB). The issues of energy as the industry that covers energy resources, extraction, transformation, transfer and use of various types of energy are considered. The features of an electric power station, as a set of installations, equipment and tools which are used directly for producing electric energy are highlighted as well as the necessary facilities that are located on a designated area. The features of the structure of the technology of thermal power plants are illustrated. The place of thermal power plants in the structure of power engineering is considered. The available problems of thermal power plants are revealed. The solution of problems of low efficiency, the deterioration and ageing of thermal power plants equipment is suggested. The indicators of the equipment of thermal power plants are given. The advantages and disadvantages of the old technologies used in thermal power plants of Ukraine are studied. The disadvantages of outdated equipment such as damage and constant need for reconstruction are regarded. The mechanism of introducing the new technology of the circulating fluidized bed (CFB) in comparison with the traditional flaring at domestic and foreign thermal power plants is analyzed. The advantages and disadvantages of the CFB technology in comparison with traditional flaring are considered. The **results** of the feasibility study are presented; these results provide the basis for determining the most promising objects for the implementation of this technology while retooling power plants. The effect of modernizing the equipment of thermal power plants is proved. Solutions for improving the cost-effectiveness of thermal power plants are suggested. The results of the obtained decision within this study are illustrated.

Keywords: power engineering, thermal power plant, modernization of equipment, technology of circulating fluidized bed, introduction, traditional flaring, fuel, retooling.

Introduction

Heat power engineering is a branch of heat engineering that is engaged in converting heat into other types of energy, mainly into mechanical and electrical ones. Thermal power plants are used to generate mechanical energy at the cost of heat; the mechanical energy obtained in these installations is used to drive working machines or electromechanical generators which help produce electricity. Installations that do not use electromechanical generators to convert heat into electricity are called electrical conversion units. These include magneto-hydro-dynamic generators, thermoelectric generators, thermal emission energy converters.

The basis of modern heat and power engineering is heat-power facilities of steam turbine power stations consisting that comprise a boiler and a turbine. Thermal power plants (TPP) are often built in large cities and condensing power plants (CPP) in the areas with cheap fuel.

The analysis of literary source and problem statement

The issues of retooling thermal power plants are considered in the works of many scientists, among them are M. Borisov [1], O. Maystrenko [2], S. Dubovsky [3] and O. Matiiko, N. Rodzevich, G. Gnatyuk, A. Matvienko, A. Gorshkov, Yu. Klushin, M. Kulik, Z. Geletii, A.Roskolupa, J. Misak, T. Kravets and many others.

However, it should be noted that although there is already a significant number of scientific works related to the problem of outdated equipment of thermal power plants, there still remain tasks that need to be covered and issues to be discussed.

Solid-fuel thermal power plants are an integral part of Ukrainian electric-power industry. The prospects of coal and other sectors of the national economy of Ukraine depend on the state of thermal energy.

Such problems as low efficiency, equipment deterioration and ageing, the increase of imported natural gas price under the shortage of coal-mining capacities are among the topical problems of thermal energy. The operation of thermal power plants without their modernization and introduction of new technologies leads to an increase in the share of equipment that worked out the resource and results in technological failures, an increase in the electricity cost, specific fuel consumption. Also, a significant issue in heat engineering is that thermal power plants (TPPs) have a negative impact on the environment.

The problem of the reasonable and balanced use of the enriched coal as a fuel for existing boiler units with flaring technology is of great importance today as well as the use of low-grade ordinary coal and waste coals as a fuel for new advanced technologies of "pure" burning and, in particular, in the boilers of a circulating fluidized bed (CFB).

One of the methods of solving these problems is the use of a new ecologically pure technology for solid fuel burning in CFB under atmospheric pressure. Now, this technology is used in new equipment – CFB boiler units with the capacity of 200-460 MW and they can be used with supercritical parameters.

The goal and objectives of the study are to identify the economic efficiency of modernizing TPP equipment on the basis of new technology and taking into account cost minimization and environmental requirements. The objectives of the research are to study the information base of the research, to analyze the technical and economic conditions of outdated and modern equipment of thermal power plants, to make an economic analysis of the introduction of new equipment.

Materials and methods of the study

To solve this problem, the feasible analysis was used to determine the current state of TPP equipment, the indicators of parameters of outdated and new equipment and capabilities of introducing new equipment and burning low-grade coal and waste in a circulating fluidized bed (CFB). The information base of the research is the materials of technical and economic indicators and characteristics of the equipment of thermal power plants, in particular, the Vuglegirska thermal power plant, works of domestic and foreign authors as well as scientific information posted on the Internet.

The results of the study

The introduction of a new power unit with the technology of a circulating fluidized bed will increase the productivity and power capacity of the Vuglegirska thermal power plant in the electricity market. It will also result in the growth of the company profits by increasing the efficiency of work and increasing electrical output as well as will enable retooling available main energy equipment.

The installed capacity of the power plant will be 3720 MW. The use of new power units will increase the demand for low-quality coal. Economic efficiency will be positive. Building a new power unit will enable creating new jobs for the period of building only.

The discussion of the results

The issues of modernization are topical and should be solved at the Vuglegirska thermal power plant of PAT Centrenergo. Thermal power plants are the basis of the electric power industry. Fuel that is used at TPP is coal, natural gas, residual fuel oil, shales, firewood. TPP comprise a thermal power plant fuel system and pulverized fuel system; boiler equipment – a set of a boiler and auxiliary equipment; water treatment facilities and condensate systems; service water system; the system of ash handling and slag disposal; electrical and technical facilities; electric equipment control system.

The design capacity of the Vuglegirska TPP is 3600 MW, particularly – the first line units are four 300 MW coal-based generating units adapted for running on natural gas, the second line units are three 800MW oil/gas units. The construction of the power plant started in 1968. The first unit of 300 MW capacity was put into operation in December 1972, the construction of the first stage finished in 1973, the second one was completed in 1977. The TPP is located in the Donetsk region, on the left bank of the reservoir impounded on the river Lugan.

The TPP main facilities are the main building of I and II lines; a joint auxiliary building; fuel facilities; oil / residual fuel facilities; drinking and service water objects and systems of ash handling and slag disposal; electrical and technical facilities; sewage disposal plants. The thermal circuit of the TPP arrangement provides the block principle of operating without cross connections among power units along the main lines. In the main building, there is a plant central control board, two unit switchboards for 300 MW 4 units and three unit switchboards for 800 MW 3 units (table 1).

Operating capacitance in 2016 is 2432,2 MW with planned 2385,9 MW.

Table 1. *Short characteristic of the equipment of 300 and 800 MW units*

			300 MW power unit	800 MW power unit
Boilers	single-body boiler unit with industrial steam superheater	type	ТПП-312А	ТГМП-204
		factory	Taganrog boiler factory	Taganrog boiler factory
		fuel	ГСШ coal, gas	gas, residual fuel oil
		exhaust conditions	255 kp/cm2 / 545 °C / 545 °C	255 kp/cm2 / 545 °C / 545 °C
		steam flow rate	950 t-hr	2650 t-hr
		number of burners	8	36
	power unit	turbine drive	ОР-12РМ	ОК-18PU
		feed pump: - primary - startup and standby	 ТПН -1150-340 ПЭ-600-300-2	 ПН -1500-350- 2 pcs. -
		booster pumps	12ПД-8 - 3 pcs.	
	regenerative air heater	type	РВП-98 - 2 pcs.	РВП-98 - 4 pcs.
	forced-draft installation	smoke exhauster	ДОД-31,5 - 2 pcs.	-
		forced draft blower	ВДН-32Б- 2 pcs.	ВДН-32х2 with a turbo drive ОР-12пв - 2 pcs.
	pulverized fuel system	ball-mill pulverizer	Ш-50А - 2 pcs. for 75 t of coal each	-

The end of the **Table 1**

1	2	3	4	5
	electrical precipitation filters for waste gases	type	ЭГА-2-58-12-6-3 - 2 pcs.	-
Turbines	primary turbine	type	К-300-240-2	К-800-240-3
		factory	Turboatom, Kharkiv	LMF, St.Peterburg
		throttle conditions	240 kp/cm2 / 540 °C / 540 °C	240 kp/cm2 / 540 °C / 540 °C
	condensing unit	condenser	К-15240 Air-15240 m2	800 КЦС-3 Air-41200 m2
		circulating pumps	ОП 2 -110ke - 2 pcs.	ОП10 –185eg- 2 pcs.
		ejectors	ЭП-3-25/75- 2 pcs. ЭВБ-801531- 1 pcs.	ЭВ7-1000- 2 pcs. ЭВ7-1700 -1 pcs.
	regeneration system	high pressure heaters	ПВ-900-380-18 ПВ-1200-380-42 ПВ-900-380-66	ПВ-1600-380-17 ПВ-2000-380-40 ПВ-1600-380-66
		deaerator	ДСП-500 - 2 pcs.	ДСП-1300 - 2 pcs.
		low pressure heaters	ПН-400-26-7- I ss ПН-400-26-7- II ss ПН-400-26-7- IV ss ПН-400-26-7- V ss	ПН-1700-32-6-I ss ПН-2000-32-6-II ss ПН-1500-32-6-III ss ПН-1500-32-6-IV ss
heat and power plant	line heaters	type	ПСВ-125-7-15 – 2 pcs.	ПСВ-200-7-15 – 2 pcs.
		overall power	15,8 Gcal-hr	25 Gcal-hr
	line pump	type	3-В-200х2 – 5 pcs. for I line	СЭ-800-100-3 pcs. for II line
electrical machinery	generator	type	ТГВ-300 water cooled	ТГВ-800-2ЕУ3 water to air cooled
		type	ТДЦ-400000/100 - at unit No. 1,2 ТДЦ-400000/300 - at unit No. 3,4	ТНЦ-1000000, ТЦ-1000000

Table 2. *Operating capacitance of the Vuglegirska TPP in 2016, MW*

Power station	Average installed capacity			Repairs			Limitations			Operating capacitance		
	Plan	Actual	L	Plan	Actual	L	Plan	Actual	L	Plan	Actual	L
Vuglegirska TPP	3600	3600	0	277,9	239,1	-38,8	136,2	128,7	-7,5	2385,9	2432,2	46,3

The increase in operational power compared to the plan caused by reducing the idle hours of the units during maintenance and repair from 277.9 MW according to the plan to 239.1 MW actually and by reducing the power limitations from planned 136.2 MW to actual 128.7 MW.

In general, all damage to the Vuglegirska TPP is caused by the outdated equipment. The equipment was disabled because the sides of the pipe excessively thinned, the metal pipe corroded, the pipe was manufactured with technological defects, the pipe metal was ashed metal damage as well as due to corrosion damage and the micropores of welded joints, corrosion damage and so on. The lifetime of the damaged equipment is long and the equipment requires timely repair or replacement.

That is why modernizing the main mechanical and mechanical equipment of the Vuglegirska TPP is an urgent task.

Table 3. *Technical and economic indicators of the Vuglegirska TPP in 2015-2016*

	Specific consumption of fuel equivalent for electricity supply, g/KW-h			Specific consumption of fuel equivalent for heat supply, kg/Gcal			Power consumption for generating electricity, %			Power consumption for for generating heat, KW-h/Gcal		
	2015 actual	2016		2015 actual	2016		2015 actual	2016		2015 actual	2016	
		actual	stand.		actual	stand.		actual	stand.		actual	stand.
Power plant	378,5	383,7	383,7	123,9	126,0	126,0	7,26	7,25	7,35	36,66	36,34	36,34
300 MW power unit	378,5	383,7	383,7	123,9	126,0	126,0	7,26	7,25	7,35	36,66	36,34	36,34
800 MW power unit	-	-	-	-	-	-	-	-	-	-	-	-

In 2016 the specific consumption of equivalent fuel for the electricity produced by the TPP in general and by I line (300 MW units) was 383.7 g/KW-h (Table 3) compared to 378.5 g / kWh in 2015, while the standard rate in 2016 was 383.7 g/KW=h and the rate planned by the National Joint Company "Energy Company of Ukraine" was 383.7 g/KW-h.

The increase in the specific consumption of equivalent fuel for the electricity produced by the TPP in general and by I line (300 MW units) compared to the consumption in 2015 was 5.2 g / kWh.

The most important reason for increasing the specific fuel consumption for the electricity produced by I line (300 MW units) in 2016 versus 2015 was the increase of heat input to support the viability of 800 MW units when they stopped because of technological needs and weather conditions.

800 MW units did not operate in 2016 році.

In 2016 the specific consumption of equivalent fuel for producing heat in 2016 was 126,0 kg/Gcal versus 123,9 kg/Gcal in 2015 while the standard rate in 2016 was 126,0 kg/Gcal.

The comparative analysis of specific consumption rate for producing electricity and heat in 2016 and 2015 is given in Table 3.

Actual losses of electricity for own needs at the TPP in 2016 were 7,25 % versus 7,26 % in 2015, while the standard rate in 2016 was 7,35 %.

The reduction of actual electricity consumption for own needs is caused by increasing the number of working units from 2,27 in 2015 to 2,37 in 2016 and by increasing the average load from 231 MW in 2015 to 234 MW in 2016.

The comparative analysis of losses for own need in 2016 and 2015 is given in Table 3.

The economy of actual expenses of electric power for own needs versus standard losses in 2016 is 4712 ths. kW/h.

Let us consider the efficiency of the replacement of the outdated TPP boiler 312A with a new one, i.e. ЦКШ in economic terms (Table 4).

Table 4. *Characteristics of the boiler equipment of Ukraine and China*

Boilers	Start-up year	Power capacity, MW	Efficiency, %	Country
ТПП 312А	1973	300	88,5	Ukraine
АЦКШ	2017	330	92,5	China

The total cost of new equipment is 4 000 000 000 UAH. The annual profit of the new power unit is 1 000 000 000 UAH. The efficiency of a modern boiler is 92,5%, instead of 88,5% of the outdated one. After four 300 MW units were replaced with four 330 MW units, operating capacity of the power plant will be 3720 MW instead of 3600 MW.

The cost of fuel is considerably low due to its low grade. Thus, a tonne of anthracite coal will cost 1,200 UAH / ton, when earlier the price of 1 tonne was 1743.7 UAH / tonne.

$$Cost_б = 1743{,}7 \times 2000000 = 3487400000 \text{ UAH/year.}$$

$$Cost_н = 1200 \times 2000000 = 2400000000 \text{ UAH/year.}$$

Economies in fuel is: 3487400000 – 2400000000 = 1087400000 UAH/year

The cost of new equipment is 1 000 000 000 UAH. Four new boilers are needed.

Thus, the following result is obtained:

- the expenses for mounting the equipment are 4 000 000 000 UAH.

- the profit from saving in fuel is 1 087 400 000 UAH / year.

To determine economic efficiency, the formula for calculating the classic indicator of Net Present Value (NPV) should be used.

In this paper the total value of CFi (NPV) will be designated as the sum of profits and amortization:

$$CF_i = P + A \tag{1}$$

where P is the company profit;

A is the amortization.

CF_i = 1 000 000 000 + 160 000 000 = 1 160 000 000 UAH/year

First, net present values are calculated according to the formula [16] (Table 5):

$$\frac{\sum CF_i}{(1+r)^t} \tag{2}$$

where CF_i is monetary flows arranged by the years;

r is the discounting rate (15%);

t is the year in succession;

Then, for the first year, the net present value is

$$\frac{\sum CF_i}{(1+r)^t} = \frac{160000000}{(1+0{,}15)^1} = 966666667 \text{ UAH.}$$

The net present value is calculated according to the formula:

$$NPV = \frac{\sum CF_i}{(1+r)^t} - I\ , \tag{3}$$

where I is the amount to be invested;

$\frac{\sum CF_i}{(1+r)^t}$ is the amount of net cash flows;

$\frac{\sum CF_i}{(1+r)^t}$ = 4 389 999 925 (Table 5);

NPV= 4 389 999 925– 4 000 000 000 = 389 999 925 грн.

In this case, NPV is positive.

The excess present value index is calculated according to the formula:

$$PI = \frac{\sum CF_i}{(1+r)^t} / I. \tag{4}$$

Then the excess present value index will be equal to 4 389 999 925/ 4 000 000 000=1,09.

If the excess present value index is greater than 1, changing the equipment is an efficient solution.

Table 5. *NPV calculation*

Years	Amount to be invested, UAH	Monetary flows, UAH (CF)	Net cash flows, UAH	Net present value, UAH (NPV)
2017	4 000 000 000	1 160 000 000	1 008 695 652	-2 991 304 348
2018		1 160 000 000	877 126 654	-2 114 177 694
2019		1 160 000 000	762 718 830	-1 351 458 864
2020		1 160 000 000	663 233 765	-688 225 099,3
2021		1 160 000 000	576 725 013	-111 500 086,3
2022		1 160 000 000	501 500 011	+389 999 925
Всього	4 000 000 000	6 960 000 000	4 389 999 925	+389 999 925

Payback period (discounted) will last longer than 5 but less than 6 years. The exact value can be calculated by the formula:

Payback period (discounted) = 5 + (remaining investor debt by the end of the 5th year) / net cash flow for the 6th year.

Payback period = 5 + 111 500 086.3 / 501 500 011 = 5.22 years.

Therefore, in less than 6 years the company will fully cover the cost of equipment only at the expense of buying low-grade fuel.

The fuel component of the cost of electricity in 2016 was 69.9 kopecks / kW. After the implementation, this indicator will be far less.

Despite the higher cost of mounting such boiler equipment, CFB boilers have a number of advantages. First of all, they are environmentally friendly due to efficient multi-polar electrical precipitation filters used for separating flue gases from solid particles, the efficiency of such filters is practically equal to 100%.

In addition, the boiler with CFB is economical as it has a higher efficiency when operating on low-grade energy fuels due to the fact that unburned fuel particles are returned to the combustion chamber mixing with a new fuel delivery. It is important that the CFB technology enables using low quality fuel with high ash content.

Thus, putting into operation new electric units with the capacity of 330 MW can improve the characteristics of the Vuglegirska TPP.

Retooling the blocks according to the new technology of burning low-grade coal or mud coal in CFB boilers will significantly improve the technical and economic performance of the power station, will reduce social tension in the Donbass region by providing the regional population with jobs, will improve the environmental condition of the area [14]. Building the boiler will allow Ukrainian experts to improve their professional skills and acquire experience in the process of constructing, designing, manufacturing and mounting the equipment as well as building.

Conclusions

At the present stage, the thermal energy of Ukraine is in critical condition because of the deterioration of the main technological equipment, the lack of manoeuver capacity as well as the large environmental impact. This condition can be improved by upgrading equipment. Such retooling should be carried out using new boilers with circulating fluidized bed which are already used abroad and at some thermal power plants in Ukraine.

This technology ensures high efficiency, environmental cleanliness, reliability and manoeuverability of modern TPPs. Such technology is the most promising method for reconstructing and building new power units of thermal power plants.

It is worth noting that this technology enables burning coal together with peat and biomass, which is an interesting and advanced technical solution for implementing such projects in Ukraine.

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Receive 20.10.2017

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ЕКОНОМІЧНА ЕФЕКТИВНІСТЬ МОДЕРНІЗАЦІЇ ОБЛАДНАННЯ ДЛЯ ТЕПЛОВИХ ЕЛЕКТРОСТАНЦІЙ

Темою дослідження є економічна ефективність модернізації обладнання для теплових електростанцій. **Метою** роботи є виявлення економічної ефективності з модернізації обладнання ТЕС на основі використання нової технології та з урахуванням мінімізації витрат та виконання екологічних вимог. **Предметом** дослідження є теоретичні та практичні аспекти економічної ефективності модернізації обладнання. Для знаходження рішення даного питання необхідним було використати техніко-економічний аналіз, який використовувався для визначення сучасного стану обладнання ТЕС, для показників параметрів старого та нового обладнання, а головне для впровадження нового обладнання та можливості спалювання низькосортного вугілля і відходів вуглезбагачення в циркулюючому киплячому шарі (ЦКШ). Розглянуто проблеми енергетики, як галузі господарства, котра охоплює енергетичні ресурси, добування, перетворення, передачу і використання різноманітних видів енергії. Висвітлено особливості електричної станції, як сукупності установок, обладнання та апаратури, які використовуються безпосередньо для виробництва електричної енергії, а також необхідних для цього споруд та будівель, розташованих на певній території. Висвітлено особливості структури технології теплових електростанцій. Розглянуто місце теплових електростанцій в структурі енергетики. Виявлено сучасні проблеми теплових електростанцій. Запропоновано рішення проблем низької ефективності, зношення та старіння обладнання теплових електростанцій. Наведено матеріали показників обладнання теплових електростанцій. Досліджено переваги та недоліки старих технологій, що використовуються на теплових електростанціях України. Висвітлено недоліки старого обладнання у вигляді пошкоджень та постійної потреби у реконструкції. Проаналізовано механізм впровадження нової технології циркулюючого киплячого шару (ЦКШ) в порівнянні з традиційним факельним спалюванням палива на вітчизняних та зарубіжних теплових електростанціях. Розглянуто переваги і недоліки технології ЦКШ в порівнянні з традиційним факельним спалюванням палива. Наведено **результати** техніко-економічного аналізу, на основі яких визначено найбільш перспективні об'єкти для впровадження цієї технології при технічному переозброєнні електростанцій. Знайдено ефект від модернізації обладнання теплових електростанцій. Винайдені рішення для покращення економічної ефективності теплових електростанцій. Висвітлені результати отриманого рішення даного дослідження.

Ключові слова: енергетика, теплова електростанція, модернізація обладнання, технологія циркулюючого киплячого шару, впровадження, традиційне факельне спалювання, паливо, реконструкція.

ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ МОДЕРНИЗАЦИИ ОБОРУДОВАНИЯ ДЛЯ ТЕПЛОВЫХ ЭЛЕКТРОСТАНЦИЙ

Темой исследования является экономическая эффективность модернизации оборудования для тепловых электростанций. **Целью** работы является выявление экономической эффективности по модернизации оборудования ТЭС на основе использования новой технологии и с учетом минимизации затрат и выполнения экологических требований. **Предметом** исследования являются теоретические и практические аспекты экономической эффективности модернизации оборудования. Для нахождения решения данного вопроса необходимо было использовать технико-экономический анализ, который использовался для определения современного состояния оборудования ТЭС, для показателей параметров старого и нового оборудования, а главное для внедрения нового оборудования и возможности сжигания низкосортного угля и отходов углеобогащения в циркулирующем кипящем слое (ЦКС). Рассмотрены проблемы энергетики, как отрасли хозяйства, которая охватывает энергетические ресурсы, извлечения, преобразования, передачи и использования различных видов энергии. Освещены особенности электрической станции, как совокупности установок, оборудования и аппаратуры, используемых непосредственно для производства электрической энергии, а также необходимых для этого сооружений и зданий, расположенных на определенной территории. Освещены особенности структуры технологии тепловых электростанций. Рассмотрены место тепловых электростанций в структуре энергетики. Выявлены современные проблемы тепловых электростанций. Предложено решение проблем низкой эффективности, износа и старения оборудования тепловых электростанций. Приведены материалы показателей оборудования тепловых электростанций. Исследовано преимущества и недостатки старых технологий, используемых на тепловых электростанциях Украины. Освещены недостатки старого оборудования в виде повреждений и постоянной потребности в реконструкции. Проанализирован механизм внедрения новой технологии циркулирующего кипящего слоя (ЦКС) по сравнению с традиционным факельным сжиганием топлива на отечественных и зарубежных тепловых электростанциях. Рассмотрены преимущества и недостатки технологии ЦКС по сравнению с традиционным факельным сжиганием топлива. Приведены **результаты** технико-экономического анализа, на основе которых определены наиболее перспективные объекты для внедрения этой технологии при техническом перевооружении электростанций. Найдено эффект от модернизации оборудования тепловых электростанций. Изобретены решения для улучшения экономической эффективности тепловых электростанций. Освещены результаты полученного решения данного исследования.

Ключевые слова: энергетика, тепловая электростанция, модернизация оборудования, технология циркулирующего кипящего слоя, внедрение, традиционное факельное сжигание, топливо, реконструкция.