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ТЕПЛОФИЗИКА И ТЕОРЕТИЧЕСКАЯ ТЕПЛОТЕХНИКА

THERMOPHYSICS AND THEORETICAL THERMOENGINEERING

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Study of Kazakhstan`s coals burning efficiency of long-term combustion boilers up 100 kW

Today more than 30 % of boiler equipment in Kazakhstan has an increased moral and physical deterioration. The replacement of this equipment is made mainly by high-quality equipment of foreign manufacturers. However, boilers of foreign manufacturers are designed, as a rule, for operation on coals or other types of solid fuel with improved characteristics or fuel, which requires additional preparation. This ultimately reduces the operational and economic characteristics of the boiler and increases the cost of thermal energy for the consumer. Kazakhstan has a sufficient amount of solid fuel, which is possible for use in small-capacity boilers. However, most of this fuel is of poor quality. It seems to use low-quality coals in long burning boilers promising. When operating such boilers, additional heat is generated through the generation of synthesis gases generated in such boilers. To date, the production of long burning boilers is developing widely among domestic producers. Boilers of prolonged burning are becoming more and more popular. Analysis of the use of long burning boilers showed that when burning low-grade coals, their efficiency reaches 96-98 %. Low-power heating boilers of traditional designs with the use of coals of improved characteristics have an efficiency of not more than 90 %. However, to date, there are no regulatory documents that regulate the performance characteristics of long burning boilers. Therefore, finding the optimal characteristics of the efficiency of fuel combustion, taking into account the standardized indicators, the question is very important, which determines the reliability, environmental friendliness and economical operation of the boiler. The analysis of the application of Kazakhstani fuels on long burning boilers with a capacity of up to 100 kW has been conducted and possible ways of improving the efficiency of these boilers have been determined.

Keywords: Kazakhstani coals, long burning boilers, operating characteristics, boiler power grid, fuel combustion efficiency, ash content, fuel combustion heat, emissions of harmful substances, mechanical underflight.

Organic solid fuel for heat supply of the housing, administrative and agro-industrial sector buildings and structures in Kazakhstan is applied by more than 74 %. Most of the kazakhstan`s coals are low-quality coals (high ash content, sulfur content, large volatile yield). In this regard, interest to heating boilers that efficiently burn low-grade fuels is relevant [1].

Long burning boilers are working on solid fuels and carry out most of the individual heat supply in Kazakhstan. These boilers are working in accordance to GOST20548-87. Water heating Boilers, capacity up to 100 kW. General technical conditions (GOST). Such boilers use coal, pellets, peat bricks and other types of solid fuel. However, the conditions for the combustion of fuel in, long-term boilers differ from the conditions for the combustion of fuel in boilers presented in the GOST.

These conditions must be taken into account when determining the efficiency of fuel combustion. In long-term boilers the fuel burns slowly in a «thick» layer - the initial height of the layer after loading can reach 0.8 m or more [2, 3]. Air for combustion enters the boiler by means of a vacuum. The vacuum is creat-

ed by the natural draft of the chimney or by a blower, which is installed depending on the design of the boiler in the upper or lower part of the boiler. Regulation of air supply in such boilers is carried out automatically, or by means of an air damper.

The duration of the working cycle is 7 days or more. For one cycle, no more than 5 kg per hour is used if coal of poor quality is used. Therefore, the maximum heat output of boilers operated on low-grade coal does not exceed 25 kW.

$$Q_{\max} = BQ_n \eta,$$

The heating capacity of the boiler according to GOST at this load is inversely proportional to the duration of work on one fuel charge:

$$Q = \frac{MQ_n \eta}{T},$$

where M — total fuel consumption, kg; Q_n — heat of combustion of fuel, kJ / kg; T — continuity of the working cycle, hour; η — efficiency of the boiler, %.

The maximum capacity of the boiler can be achieved with a fully open air damper with the greatest excess of air. While the duration of the working cycle will be minimal. And, conversely, with the minimum heat output of the boiler, the maximum duration of its operation is reached.

In this regard, the designation of the rated output of the boiler without indicating the duration of the boiler operation in the GOST and the boiler's passports is incorrect. For this reason, the boiler power values in the GOST and the manufacturer's passport data are not unambiguous.

Mechanical incompleteness of combustion of fuel in designs of small-capacity heating boilers always leads to large losses with fuel failure, slag and entrainment. As a result, the efficiency of hot-water boilers up to 100 kW in accordance with GOST does not reach 70 %.

The designs of long-term boilers have today a higher efficiency, but they also have common drawbacks:

1) The duration of work on one fuel load T is limited by the volume for its placement. With a grate area $R = 0,13-0,15 \text{ m}^2$ and a layer height $H = 0,45 \text{ m}$, not more than 45-50 kg of fuel can be accommodated;

2) The maximum boiler output is limited due to unprocessed air supply processes;

3) The operation of the boiler during the heating cycle is uneven. There is an uncontrolled increase in power, and then a decrease due to a decrease in the aerodynamic drag of the coal layer during its burn-out and changes in thrust in the chimney;

4) In the case of using stone or brown coal, heating flue surfaces are inefficiently used. The heat perception of the boiler occurs only in that part of the layer where the burning site is located. In the case of a boiler with a lower air supply, there will be no burning at the top of the combustion layer and the temperature will not exceed 200 °C;

5) The operation of the boiler is intensively accompanied by uncontrolled emissions of CO and CO₂ [4, 5].

Analysis of the long-term boilers operation has shown that the main drawbacks are associated with an insufficient area of the grate R, usually not exceeding 0,13-0,15 m².

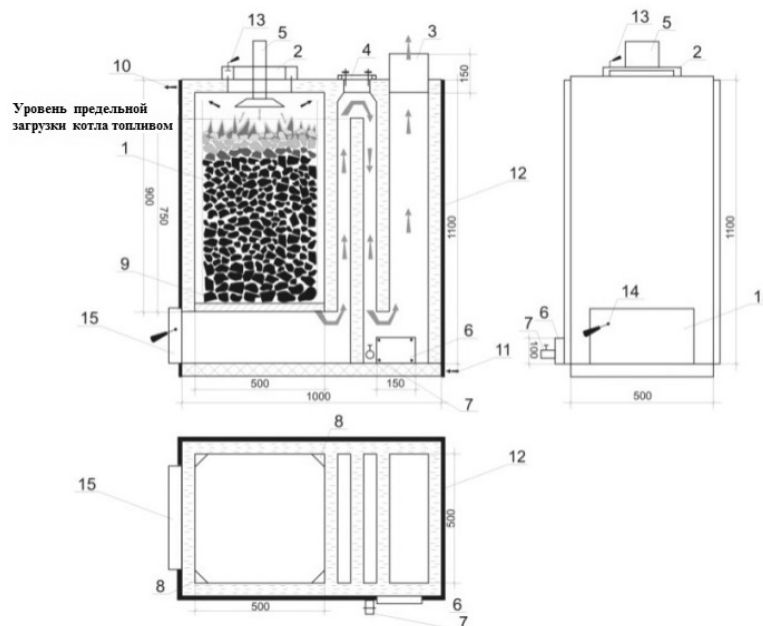
At the same time, the thermal stress of the grate BQ/R reaches 22-30 kW/m², which leads to large values of chemical and mechanical fuel burn-up [5-12].

Geometric correction of the boiler design in accordance with the air supply mode is one of the most effective methods of reducing mechanical fuel shortage in the designs of long-burning boilers when using low-quality coal of poor quality. Geometric correction promotes the creation of conditions for maximum fuel burn up in the layer when generating additional combustible gases in this fuel layer. In order to determine the possibility of creating such conditions when burning low-grade Kazakhstan coals and determining the efficiency of coal combustion, studies were conducted on a long-burning combustion boiler with an upper air supply of the «Kamkor» (Astana) design, Figure 1.

In long-term boilers with top air supply, the first upper layer of fuel is always in the combustion zone and is maximum heat release zone. In the subsequent layer behind it, due to the rise in temperature and lack of oxygen, a zone of generation of combustible gases from a layer heated with practically no air is formed.

Automatically dosed air supply will provide the necessary speed and intensity of combustion, a layered rise in temperature and conditions for the generation of combustible gases, always with the correct design of the boiler. Accordingly, there will be a qualitative process of almost complete burnout of fuel with increasing efficiency of the boiler [12].

The correct geometric design of the boiler, taking into account the air supply regime, is the determining factor for increasing the efficiency of burning low-grade coals for these boilers.



1 — boiler furnace, 2 — fuel loading door, 3 — chimney outlet, 4 — hatch for cleaning the chimney, 5 — blower, 6 — ash cleaning hatch, 7 — condensate drain cock, 8-9 — water-cooled grate, 10 — coolant outlet, 11 — coolant inlet, 12 — heat-insulating material, 13 — fuel-loading door handle, 14 — ballast door handle, 15 — sump door

Figure 1. General view of the design of the test boiler, 40 kW

Geometric characteristics of the furnace space:

1. The total area of the furnace: $F_f = 0,36 \text{ m}^2$, $V_f = 0,162 \text{ m}^3$.

2. Area of the grate: $F_g = 0.202 \text{ m}^2$.

In accordance with the conducted studies, the parameters of the boiler's power, exploited on coal coals of the deposits «Shubarkol», «Kary-Zhara» and «Maikubinsky», as the most widely used coals for low-power heating boilers in the Republic of Kazakhstan, were obtained. The fuel load for the working cycle of the boiler is 111 kg.

1) Power grid of the upper combustion boiler, power 40 kW ($V_{\text{furnace}} = 0,162 \text{ m}^3$), operating at the coal deposit «Shubarkol».

Boiler output by the heat carrier with a regulated temperature difference between the supply and return coolant according to GOST and the flow rate of the coolant is 60 l / min ($3,6 \text{ m}^3/\text{h}$)

1) $9.5 \text{ }^\circ\text{C}$ $Q = 39,6 \text{ kW}$;

2) $9 \text{ }^\circ\text{C}$ $Q = 37,5 \text{ kW}$;

3) $8 \text{ }^\circ\text{C}$ $Q = 33,4 \text{ kW}$;

4) $5 \text{ }^\circ\text{C}$ $Q = 20,8 \text{ kW}$.

The average boiler output by the heat carrier is $Q = 33,4 \text{ kW}$.

Fuel power of the boiler. Technical characteristics of the coal deposit «Shubarkol»:

- $Q_1^w = 20,18 \text{ MJ/kg}$;

- Ash medium content 10 %;

- Volatile yield - 43,5 %;

- Calculated efficiency boiler 97 %;

- Normalized efficiency from 85-98 %;

- Flue gas temperature is normalized within the limits of $120 \text{ }^\circ\text{C}$ - $140 \text{ }^\circ\text{C}$;

- The time of complete burn out of coal is 20 hours.

- Rated boiler output 38 kW;

- Peak power 39,6 kW;

- Minimum power 21,5 kW;

- Average capacity of the boiler for fuel is 33kW (330 m^2 of heated area).

Table 1

Power grid of the upper combustion boiler with a power of 40 kW operating on the coal deposit «Shubarkol»

Item No	V_f	Percent downloads boiler furnaces (by volume), %	Weight of coal, kg	Useful heat output the MJ	Power kWh h	Installed capacity during the complete combustion of coal kW
1	0,162 m ³	83	121	2844	790	39,6
		80	117	2750	764	38,2
2		60	88	2068	574	28,7
3		45	66	1551	430	21,5

2) Power grid of the upper combustion boiler, power 40 kW ($V_{\text{furnace}} = 0,162 \text{ m}^3$), operating at the coal deposit «Kary-Zhara».

Boiler output by the heat carrier with a regulated temperature difference between the supply and return coolant according to GOST and the flow rate of the coolant is 60 l/min (3,6 m³/h).

- 7,5 °C $Q = 31,3 \text{ kW}$;
- 7 °C $Q = 29,2 \text{ kW}$;
- 6 °C $Q = 25 \text{ kW}$;
- 5 °C $Q = 20,8 \text{ kW}$;
- Average boiler output by heat carrier $Q = 26,5 \text{ kW}$.

Fuel power of the boiler. Technical characteristics of the coal deposit «Kary-Zhara»:

- $Q_f^w = 19,552 \text{ MJ/kg}$;
- Ash medium content 19,8 %;
- Volatile yield - 42 %;
- Calculated efficiency boiler 97 %;
- Normalized efficiency from 85-98 %;
- Flue gas temperature is normalized within the limits of 120 °C-140 °C;
- The time of complete burn out of coal is 20 hours.
- Rated boiler output 30,8 kW;
- Peak power 31,8 kW;
- Minimum power 17,3 kW;
- Average capacity of the boiler for fuel is 26kW (263 m² of heated area).

Table 2

Power grid of the upper combustion boiler with a power of 40 kW operating on the coal deposit «Kary-Zhara»

Item No	V_f	Percent downloads boiler furnaces (by volume), %	Weight of coal, kg	Useful heat output the MJ	Power, kWh h	Installed capacity during the complete combustion of coal, kW
1	0,162 m ³	83	121	22,94	637	31,8
		80	117	22,18	616	30,8
2		60	88	15,17	421	21
3		45	66	12,51	347	17,3

3) Power grid of the upper combustion boiler, power 40 kW ($V_{\text{furnace}} = 0,162 \text{ m}^3$), operating at the coal deposit «Maikubinsky».

Boiler output by the heat carrier with a regulated temperature difference between the supply and return coolant according to GOST and the flow rate of the coolant is 60 l/min (3,6 m³/h).

- 9 °C $Q = 28,3 \text{ kW}$;
- 7,5 °C $Q = 26,2 \text{ kW}$;
- 6,5 °C $Q = 24 \text{ kW}$; (240 m²);
- 5,5 °C $Q = 18,8 \text{ kW}$;
- Average boiler output by heat carrier $Q = 24,3 \text{ kW}$.

Fuel power of the boiler. Technical characteristics of the coal deposit «Maikubinsky»:

- Q_1^w 18,4 MJ/kg;
- Ash medium content 9-18 %;
- Volatile yield 40-48 %;
- Calculated efficiency boiler 97 %;
- Normalized efficiency from 85-98 %;
- Flue gas temperature is normalized within the limits of 120 °C-140 °C;
- The time of complete burn out of coal is 20 hours.

Table 3

Power grid of the upper combustion boiler with a power of 40 kW operating on the coal deposit «Maikubinsky»

Item No.	V_f	Percent downloads boiler furnaces (by volume), %	Weight of coal, kg	Useful heat output the MJ	Power kWh h	Installed capacity during the complete combustion of coal kW
1	0,162m ³	83	121	21,94	537	26,8
		80	117	21,18	490	27,8
2		60	88	13,17	386	18
3		45	66	10,51	320	15,3

- Rated boiler output 26,8 kW;
- Peak power 27,8 kW;
- Minimum power 15,3 kW;
- Average capacity of the boiler for fuel is 23,3 kW (233 m² of heated area).

The results of the conducted experiments showed that for the same volume of the furnace and the same fuel consumption, the capacity of the long-life combustion boiler directly depends on the type of coal burnt

This corresponds to the basic theoretical provisions for heating water boilers presented in GOST.

However, the power in the boiler's passport (40 kW) at an air flow rate (4,5 m³/min) is possible only when the coal-fired boiler of the deposit «Shubarkol» is operating. When the boiler is operating on coals of the deposit «Maikubinsky» and the deposit «Kary-Zhara» even in the peak load mode, the efficiency will be 68-72 %, which is 25-29 % lower than the declared value.

The studies were carried out to determine the possibility of increasing the efficiency when the excess air factor is changed.

It was determined the completeness of the CO and CO₂ emissions in the outgoing gases during operation of the coal boiler at the deposit «Maikubinsky». At the same time, normative values of emissions of these substances were taken into account in accordance with GOST, presented in Table 4.

Table 4

Regulated values of carbon monoxide and nitrogen oxides (in terms of NO₂) in dry, undiluted combustion products for boilers up to 100 kW

Type of fuel	Content, mg/m ³	
	Carbon monoxide, CO	Nitric oxides in terms of NO ₂
Anthracite	10000	-
Coal with a volatile content of up to 17 %	24000	-
Charcoal and lignite with the volatile content from 17 to 50 %	48000	-

As a result, the CO values in the dry undiluted combustion products were determined when the boiler was operated with different values of the excess air factor.

The carried out experiments showed that at $\alpha = 1,1$ the maximum CO content is 3,14 %, which is 1,14 % higher than the CO emission standard for heating boilers with a power of not more than 100 kW.

With an excess air factor of $\alpha = 0,9$, the maximum CO content is 2,65 %, which is 0,65 % higher than the norm.

With an excess air factor of $\alpha = 0.55$, the maximum CO content is 1,77 %, which is 0.33 % lower than the standard GOST and indicates the most complete burnout of CO with the formation of additional combustible gases.

In addition, the water temperature at the outlet from the boiler at an excess air factor of $\alpha = 0,55$ increased by 30 °C, which indicates an increase in the efficiency of the boiler by 3,25 %.

The carried out researches and the analysis of results show that high efficiency of burning of fuel at low values of emissions can be reached at using the system of continuous control and regulation of a parity «fuel-air» and correct geometry of boilers of long burning in the conditions of a lack of oxygen. Studies have shown that a reduction in the excess air factor on long-burning boilers with an upper air supply to the value $\alpha = 0,55$ for the combustion of coal from the Maikubin deposit is a condition for raising the efficiency of the boiler by 3,25 %.

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100 кВт дейін ұзақ уақыт бойы жанатын қазандықтарға қазақстандық көмірлерді жағу тиімділігі мәселесін зерттеу

Қазақстандағы қазандық жабдықтардың 30 %-дан астамы бүгінгі күні моральдік және физикалық тұрғыдан тозған. Бұл жабдықты ауыстыру шетелдік өндірушілердің жоғары сапалы жабдықтарымен жүзеге асады. Алайда шетелдік өндірушілердің қазандықтары көмірді немесе жақсы қасиеттері бар қатты отынның басқа түрлерінде пайдалануға арналған. Бұл қазандықтың өндірістік және экономикалық сипаттамаларын төмендетеді және тұтынушыға жылу энергиясының құнын арттырады. Қазақстанда шағын көлемді қазандықтарда қолдануға арналған қатты отын түрі көп, бірақ көпшілігі сапасыз. Ұзақ уақыт бойы жанатын қазандықтардағы сапасыз көмірлерді пайдалану тиімді болып табылады. Осындай қазандықтардың жұмысы онда пайда болатын синтез-газдарының генерациясы есебінен қосымша жылу бөледі. Бүгінде отандық өндірушілер арасында ұзақ жылдар бойы қазандықтар өндірісі кеңінен дами бастады, ал қазандықтар көп танымал болды. Ұзақ уақыт бойы жанатын қазандықтарды пайдалануды талдау төменгі көмірді жағу кезінде қазандықтардың тиімділігі 96-98 %-ға жететінін көрсетті. Жақсартылған сипаттамалары бар көмірді қолданумен дәстүрлі дизайндағы қуатты қыздыру қазандары 90 %-дан аспайтын тиімділікке ие. Дегенмен, қазіргі уақытта ұзақ уақыт бойы жанатын қазандықтардың жұмыс сипаттамаларын реттейтін нормативтік құжаттар жоқ. Осыған байланысты стандартталған көрсеткіштерді есепке ала отырып, жанармайдың жану

тиімділігінің оңтайлы сипаттамаларын анықтау өте маңызды мәселе болып табылады. Бұл мәселені шешу қазандықтың сенімділігін, қоршаған ортаны қорғауға және үнемділігін анықтайды. Қазақстандық отындарды 100 кВт дейінгі ұзақтықты бойы қазандықтарға қолдануға талдау жүргізілді және осы қазандықтардың тиімділігін арттырудың ықтимал жолдары анықталды.

Кілт сөздер: қазақстандық көмірлер, ұзақ уақыт жанатын қазандықтар, режимдік сипаттамалары, қазандықтың қуат торы, жанармайдың тиімді жануы, күлдің мөлшері, жанармайдың жану жылудығы, зиянды заттар шығарындылары, механикалық толық жанбауы.

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Исследование вопроса сжигания казахстанских углей на котлах длительного горения мощностью до 100 кВт

Более 30 % котельного оборудования в Казахстане на сегодняшний день имеет повышенный моральный и физический износ. Замещение этого оборудования производится в основном высококачественным оборудованием иностранных производителей. Однако котлы иностранных производителей спроектированы, как правило, для эксплуатации на углях или других видах твёрдого топлива с улучшенными характеристиками или топлива, требующего дополнительной подготовки. Это, в конечном итоге, снижает эксплуатационные и экономические характеристики котла и удорожает стоимость тепловой энергии для потребителя. В Казахстане имеется достаточное количество твёрдого топлива, которое возможно для использования в котлах малой мощности. Однако большая его часть имеет низкое качество. Представляется перспективным использование углей низкого качества в котлах длительного горения, эксплуатация которых предусматривает выделение дополнительной теплоты за счёт генерации синтез-газов, образующихся в таких котлах. В статье отмечено, что на сегодняшний день производство котлов длительного горения широко развивается среди отечественных производителей и котлы приобретают всё более широкую популярность. Анализ использования котлов длительного горения показал, что при сжигании низкосортных углей эффективность котлов достигает 96-98 %. Мало-мощные отопительные котлы традиционных конструкций, даже при использовании углей улучшенных характеристик, имеют КПД не более 90 %. Однако на сегодняшний день не существует нормативных документов, регламентирующих эксплуатационные характеристики котлов длительного горения, в связи с чем выявление оптимальных характеристик по эффективности сжигания топлива с учётом нормируемых показателей — вопрос, определяющий надёжность, экологичность и экономичность работы котла. В работе проведён анализ применения казахстанских видов топлива на котлах длительного горения мощностью до 100 кВт и определены возможные пути повышения эффективности работы этих котлов.

Ключевые слова: казахстанские угли, котлы длительного горения, режимные характеристики, сетка мощности котла, эффективность сжигания топлива, зольность, теплота сгорания топлива, выбросы вредных веществ, механический недожог.

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