UDC 62-626.42 DOI: 10.18372/0370-2197.1(98).17364

I. I. OBODOVSKYI, V. S. MOROZOV

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

THE PROJECT OF FURNACE FOR INDUSTRIAL WASTES DISPOSAL

The article describes the real existing project of the furnace performed on the facilities of the Secret-Service metal works company located in the Kyiv Region. It was ordered by a local waste disposal company that imports RDF and accepts garbage from the vicinity and produces RDF by itself as well. The purpose of this article is to show the opportunities of application of the quite simply designed furnace for the purposes of wastes disposal either on enterprises or within a range of an average town. The current project was implemented in reality, allowing getting rid of industrial and household garbage within the ecologic laws of the Ukraine, including the disposal of plastics, rubber, packages, etc. The proposed example of successful pyrolysis technology application in the furnace can be a good basis for further research dedicated to the creation of more advanced furnaces' types and also to the creation of the additional afterburner furnace.

Key words: *wastes disposal, furnace, pyrolysis gas, RDF (refuse derived fuels), flammable materials*

Introduction. This project is also a part of a major research of the properties and opportunities of pyrolysis gas applications in different spheres of life, performed by authors. The on-growing population of Kyiv city and its agglomeration – the satellite towns such as Brovary, for example, results to the constantly increasing amounts of household wastes and industrial ones, too.

Both cities spend a certain sum of finances from their budgets to transport the trash away from city borders. However, the trash is usually transferred to the closest trash gathering facility without any further recycling or correct disposal. There exists a private company (the owner of which has kindly asked the author not to mention its name) in vicinity of the Brovary town, which started its operation in 2019, and it is capable to perform the official wastes disposal along with giving respective certificates to its clients. The company owner has purchased a shredder that allows transforming typical household and industrial trash into the mix of pieces (RDF) that is stored in a special place of the factory. He has also ordered a furnace with pyrolysis afterburner for the opportunity of burning the trash so that there would be lowest possible emission of harmful gases into the atmosphere by means of application of previously mentioned afterburner. According to the paragraph 20 of the Law of Ukraine "About the Athmospheric Air Protection" [1], the direct burning of household wastes by citizens or enterprises in Ukraine is allowed just in case of application of special appliances which correspond to the requirements of the above mentioned law. An example of such appliance is going to be shown in this article. It would allow not only to dispose the wastes within the ecologic law of Ukraine, but also to bring certain economic benefit for plants and cities of Ukraine.

The analysis of existing research. The author has already performed basic research on application of the RDF as a fuel for pyrolysis gas generators. [2] Since RDF is quite suitable for gasification, it it is even more suitable for simple burning in furnace. As a basis for the furnace design it makes sense to look over typical household furnaces and wooden heaters constructions. [3]

On fig. 1 a scheme of the simplest DIY furnace is presented. Since it was designed for the indoor installation (e.g. inside a house), it is equipped with few elements for the users' safety assuring. The list of these elements includes struts (7-9), protection screens (13), heat exchanger (3). These elements are likely to be installed on industrial used furnace, but are not obligatory.

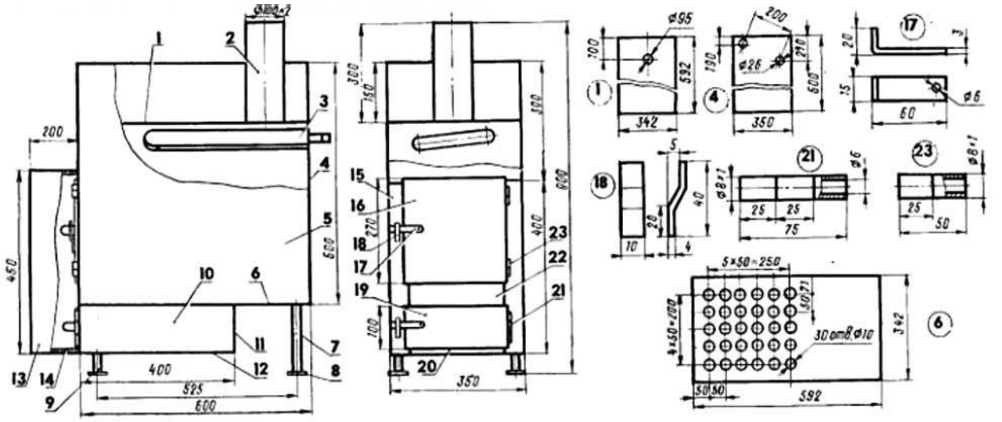

Fig. 1. Household furnace design example: *1* – smoke pipe basement sheet with an orifice, *2* – smoke pipe, *3* – heat exchanger; *4* – aft sheet of metal with heat exchanger connection points, *5* – side wall sheet; *6* – furnace basement sheet, *7* – strut, *8* – strut base, *9* – strut, *10* – ash box wall, *11* – ash box aft wall; *12* – ash box basement sheet, *13* – thermal screen wall, *14* – thermal screen basement, *15* – front wall side sheets, *16* – combustion chamber door, *17* – door lock, *18* – clamp, *19* – ash box door, *20* – front wall lower part, *21* –door hunge hub, *22* – front wall middle part, *23* – hub

However, there is no more difference between the private used and industrial furnace. It is going to have a construction similar to one depicted on pic. 1, and would have the following elements: combustion chamber, exhaust pipe, combustion chamber door, ash chamber with separate door, air supply system, smoke afterburner.

Prior performing the calculations of the furnace, it is necessary to get an understanding of materials that are planned to be burned there. Since household wastes are actually a mix of a variety of items, it means that all these different materials are going to be burned in a combustion chamber taking into a count that all of them have a different combustion temperature. This is why a certain assumption is made for this case. The sense of the assumption is that all wastes are going to be shredded into the RDF (Refuse Derived Fuel). This term is used to describe a mix of shredded household wastes along with paper, cardboard, grass, plastics, leaves, etc. But the main pecularity of the RDF is that it is allowed to be burned even in the EU which has much more strict ecology laws, comparing to Ukraine. [4]

Thus, the RDF is taken as a standard fuel for the furnace parameters' calculations. A typical enterprise works by standard 8-hour schedule, 5 days a week, i.e. a furnace would be operated 40 hours a week. On average, from 2 to 5 tones of various wastes could be delivered/produced on the enterprise each day. Let's assume that 100 cubic meters of wastes is going to be burned each day on the plant.

Aim of the work. The aim of this project is to show the opportunity of commercial application of RDF as a fuel for heaters in order to maintain the highest level of correspondence to World's and Ukrainian latest ecology laws

Idea of the work. The idea of this work is to design a simple furnace for not large waste disposal enterprise, using cheap materials, available at any local construction store and a few leftover spare parts, i.e. using cheap, reliable, quickly available materials and components. Also, this furnace will be a way of city wastes disposal according to the latest ecologic laws of Ukraine and the EU.

Problem statement. A simple burning of any trash or any other flammable material in a simple furnace is conducted under the atmospheric pressure, non-constant air supply and incorrect fuel-to-air ration. All these factors lead to the incomplete burning of the fuel. This creates a dense black smoke which is actually a mix of air and non-burned solid particles which is the main problem that is supposed to be solved by means of the designed furnace application of the wastes disposal facility.

Potential limits. The sizes of a furnace are limited by the workshop facility where it is going to be manufactured. Thus, the length & width must not exceed 3m, height must not exceed — 4м (these dimensions are limited due to the sizes of welding table and the workshop door). Also, another parameter must be taken into a count and it is a size of a fork loader and it is equal to 2m.

The Steel 30 (C1030) is chosen as a construction material of the furnace. It is a popular widespread and cheap material from which lots of metal items are produced. The current project requires application of 5 mm sheets. The other furnace elements are going to be made out of ANSI 201 stainless steel, since there exists even a greater variety of standard items out of this material as well.

The explanation of the idea. The novity of the proposed research is to apply the fan blowers and pyrolysis afterburner chamber in the furnace design.

Taking into a count the available dimensions of the combustion chamber produced out of standard sized 2x2 m sheets, there exists an opportunity to calculate the heating power of the furnace [5]. The volume of the combustion chamber is 8 m^3.

The heating capacity of household furnaces, similar to the described in this article is calculated by means of the empiric formula:

$$P = V_{furnace} \times \Delta T \times K$$

where ΔT is the difference between the magnitude of ambient temperature (or the temperature of a place where the furnace is standing) and the temperature which is reached during the wastes burning (in our case it has been measured by means of the pyrometer and had reached approximately 495°C); The K parameter is a heat-flux dispersion coefficient the valus of which that have been experimentally determined as well. The magnitude of this coefficient depends on the availability of heat isolation of the furnace and/or of the place where the furnace is located. The value of this coefficient equals 4 for metal made furnaces. Therefore, the heating power of the furnace equals:

$$P = 8 \times 4 \times (660 - 15) \approx 15795\ (kcal/hour)$$

$$P = 15795 \div 860 = 18.366\ (kWt)$$

Such a temperature inside the combustion chamber can be reached only by means of air supply. The air circulation of the furnace will be provided by two fans. An intel fan of a greater power would do the main function – air pumping in order to enrich the combustion chamber with oxygen, increase the combustion temperature and as a result – to achieve almost full burning of the material. The second fan that could be of lower power has an important role to eliminate the vortex air movement inside the combustion chamber. Together both these fans would create the laminar air flow and also make hard unburned particles of material to stay longer insidecombustion chamber in order to be afterburned. The following calculations are performed to evaluate the volume of air that is required to burn the above mentioned volume of trash (RDF) during the work day – 100 м^3.

The approximate interrelation of flammable materials in the household trash is presented in the following diagram on fig.2 [6].

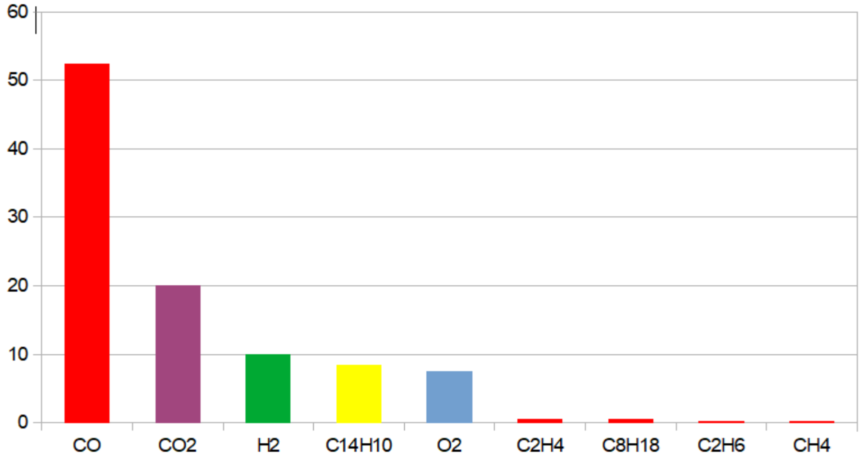

Fig. 2 Percentage of pyrolysis gas components

Taking into a count the data of diagram 1 the volume of air required to burn 1 м^3 of trash/RDF is equal to:

$$V_0 = \frac{1+K}{100} \times \left(0.5CO + 0.5H_2 + 1.5H_2S + \left(m + \frac{n}{4}\right) C_m H_n - O_2\right)$$

$$V_0 = 0.0476 \times \left(0.5 \times 40 + 0.5 \times 5 + 1.5 \times 5 + \left(1 + \frac{1}{4}\right) \times 30 - 5\right) = 9.115(m^3)$$

where К is the coefficient of air components interrelation and is the constant value due to the nature of air components (79% of nitrogen; 21% of oxygen):

$$K = \frac{V_{N_2}}{V_{O_2}} = \frac{79}{21} = 3.762$$

Therefore, it is necessary to find an electric motor for the fan that would allow pumping of 100 м^3 air into the combustion chamber. And also to calculate fan & air supply channels' parameters.

There were two available electric motors on the enterprise where the furnace was produced, both of 1800 Wt power. The customer who ordered the projected furnace has made a decision to use these motors. Thus, it is required to design a rotary blower & air velocity that it produces taking into a count the available metal items out of Steel 30 for air supply channel manufacturing. There exists a rectangular profile tube of size 200×200×6 mm, which is one of the biggest among those produced on Ukrainian metal plants. Therefore, the parameters of blower would be calculated basing on the cross-section sizeof an air supply channel made out of this tube. The air velocity is determined at first [7]:

$$V = \frac{Q}{S \times 3600}$$

$$V = \frac{100}{0.04 \times 3600} = 0.694(m/sec)$$

After that, so called blower velocity coefficient is determined:

$$n_s = 53\frac{L^{0.5} \times \omega}{P^{0.75}} \approx 43$$

Its value is rounded to the integer and it determines the air inlet diameter, which finally allows the blower CAD designing (fig.3):

$$D_{inlet} = K\sqrt[3]{\frac{L}{\omega}}$$

$$D_{inlet} = 1.75\sqrt[3]{\frac{100}{300}} = 0.56(m)$$

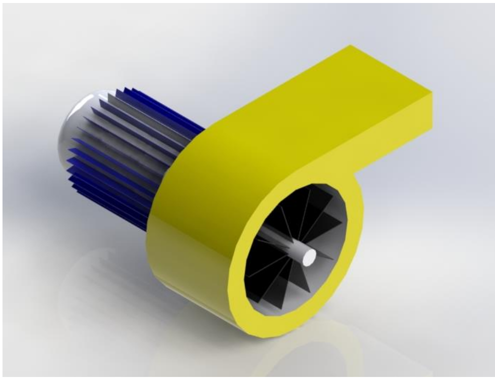

Fig. 3 The designed fan blower

After the blower design there also exists a necessity of designing the exhaust pipe equipped with a pyrolysis afterburner chamber. In this case the design is based on the standard parameter – a size of the stainless tube which is equal to 324 × 2 mm. Now the sizes of afterburner can be determined. The chamber height is [8]:

$$H = \sqrt{\frac{A \times M_i \times F}{(c_1 \times c_2) \times \sqrt{V \times T}}}$$

where A is meteorologic parameter that is taken from the annual catalog. For the Northern Ukraine its value is equal to 160; M_i is a mass of smoke that goes through the smoke vent; F is the coefficient of solid particles dropping velocity which is equal to 20 in this case; C_1 and C_2 are values of the concentration of materials in the smoke that must be transferred out through the smoke vent (both are also taken from the catalogue); V is the volume of gases that are blown from the furnace; T is the difference between temperatures of air inside the combustion chamber (where the smoke pipe begins) and on the outlet part of smoke pipe. Thus:

$$H = \sqrt{\frac{160 \times 12.3 \times 20}{(4 \times 1) \times \sqrt{10 \times 400}}} = 2.78(m)$$

Taking into a count the data of the diagram 1 it is possible to make an assumption that the 40 m^3 of carbon monoxide are going to pass through the smoke vent. Therefore, it is possible to calculate the volume of a pyrolysis chamber for after-burning this amount of flammable gas.

Since the values of heating power and smoke vent sizes were estimated above, it is possible to determine the heat density of the smoke pipe surface:

$$U = \frac{P}{S}$$

$$U = \frac{18.3}{2.83} = 6.46(kWt/m^2)$$

Thus, according to the combustion chambers calculation manual [9] there exists a possibility of cylindrical combustion chamber maximum diameter calculation:

$$U = \frac{Q}{D_{max} \times p_{air}}$$

where p_{air} is the air pressure at the combustion chamber inlet. Since the air supply velocity caused by blower does not pressurize the air, its pressure changes due to heating only and is calculated by the following way:

$$p_{air} = \frac{T \times R \times v}{V}$$

$$p_{air} = \frac{817 \times 8.314 \times 2}{8} \approx 1.7(kPa)$$

Therefore, the maximum combustion chamber diameter would be equal to:

$$D_{max} = \frac{Q}{U \times p}$$

$$D_{max} = \frac{12000}{1600 \times 6460} \approx 1.1(m)$$

Taking into a count all performed calculations there exists an opportunity to make a CAD modeling of the furnace (fig. 4) and technological documentation for manufacturing the furnace. The photo of a real made furnace is presented on fig. 5.

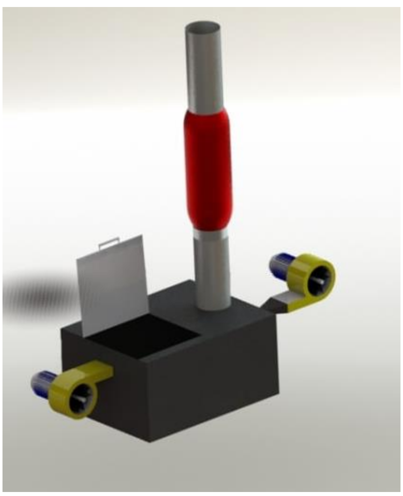

Fig. 4. The CAD model of the designed furnace

Fig. 5. The designed furnace

The obtained furnace project was implemented in life and was tested for burning the RDF. The RDF was loaded either as it is, or in the form of pressed bricks.

The afterburner size was enough to crack the solid particles causing the emission of almost transparent hot gas out of the smoke pipe when the furnace door was closed, it was fully loaded and burned for 10-15 minutes till the temperature used to rise till maximum measured values of 580-610 degrees. However, once the worker was opening a furnace door to load the next batch of the RDF, the temperature inside the combustion chamber was dropping rapidly to 300-400 degrees due to quick ambient air supply. The temperature decrement caused incomplete burning of the previous RDF batch remains while the new one was being loaded and for this short 3-7 minutes period dark smoke was being emitted from the smoke pipe.

This fact means that there is a necessity to design the separate afterburner for the smoke that would allow constant operation of the appliance without emitting harmful gases during the fuel loading.

Conclusions. The created furnace would allow enterprises to get a possibility of quick wastes disposal without the necessity of wastes logistics to the recycling factories. The wastes would be burned with the emission of the minimum amount of harmful gases into the atmosphere due to the presence of a pyrolysis combustion chamber and fan blowers that would allow the burning of 90-95% of solid particles of smoke. The heat produced by the furnace can be freely used to heat the industrial facilities where it would be located.

Referenses

1. Zakon Ukrayiny “Pro okhorony atmosfernogo povitria” [The Law of Ukraine “About the Athmospheric Air Protection”] - https://zakon.rada.gov.ua/laws/show/2707-12#Text (востаннє відкрито 09.01.23)

2. I. I. Obodovskyi, V. S. Morozov. Ohliad ta analiz istorychnykh ta suchasnykh tekhnolohii ta napriamkiv vykorystannia piroliznoho hazu v pobuti ta promyslovosti [The overview and analysis of historic and modern technologies of household and industrial pyrolysis gas application.] “Problems of friction and wear” of National Aviation University, Kyiv, 2021. PP.3-5 (in Ukrainian)

3. Simple DIY wood stove from sheet steel - https://www.pinterest.com/pin/51439620735627724/(востаннє відкрито 10.01.23)

4. The EU Ecology Directorate Report Regarding the RDF Burning, 2003 - https://www.cms-lawnow.com/ealerts/2003/09/eu-environment-directorate-report-on-refuse-derived-fuel?cc_lang=de (востаннє відкрито 09.01.23)

5. The calculation of the heat power - https://www.omnicalculator.com/physics/watts-to-heat/ (востаннє відкрито 10.01.23)

6. I. I. Obodovskyi, V. S. Morozov. Avanproekt richkovogo katera-buksyra z sylovoyu ustanovkoyu na piroliznomu gazu [THE PRELIMINARY PROJECT OF THE RIVER TOW VESSEL POWERED BY A PYROLYSIS GAS GENERATOR POWER PLANT] “PROBLEMS OF FRICTION AND WEAR” OF NATIONAL AVIATION UNIVERSITY, KYIV, 2022. PP.??? (IN UKRAINIAN)

7. Calculation of fan blower - https://www.netsolwater.com/how-to-design-an-air-blower-speed.php?blog=655 (востаннє відкрито 10.01.23)

8. Budivelny Normy Ukrainy. SniP 2.04.05-91*U: otopleniye, ventilyatsia I koditsionirovaniye [Building Standards of Ukraine. Standard 2.04.05-91*U: heating, vetilation & air conditioning] Kyiv,1996 - p. 89

9. Raschet I proektirovaniye kamer zgoraniya dlya gazoturbunnykh I parovykh ustanovok (rukovodiaschiy tekhnicheskiy material RTM 24.022.11—74 [The calculations and designing of combustion chambers for gas turbine and steam turbine appliances (technical guide RTM 24.022.11—74)] – Ministry of USSR for heavy, power & transport machine building, 1975

Стаття надійшла до редакції 24.01.2023.

Obodovskyi Ivan Ihorovych – PhD student, Ihor Sikorsky National Technical Univeristy of Ukraine, Kyiv, Ukraine; ivan.obodovsky@gmail.com, https://orcid.org/0000-0002-1102-7909.

Morozov Viacheslav Serhiyovych – PhD student, Ihor Sikorsky National Technical Univeristy of Ukraine, Kyiv, Ukraine*;* morozov09@ukr.net, https://orcid.org/0000-0002-9200-7028.

ОБОДОВСЬКИЙ І. І., МОРОЗОВ В. С.

ПРОЕКТ ПЕЧІ ДЛЯ ПРОМИСЛОВОЇ УТИЛІЗАЦІЇ СМІТТЯ

Стаття описує реально існуючий проект печі, виробленої на потужностях приватного підприємства з виробництва металоконструкцій “Секрет Сервіс”, розташоване в Київській області. Піч була замовлена місцевою компанією з утилізації сміття, котра імпортує РДФ, а також приймає сміття з найближчих населених пунктів для самостійної переробки в РДФ. Метою статті є показати переваги та недоліки цієї печі доволі простої конструкції, призначеної для утилізації побутового та промислового сміття в межах невеликого міста. Даний проект вже втілений в реальності та введений в експлуатацію, дозволяючи щоденно утилізувати сміття в межах чинного законодавства України, в тому числі такі типи відходів як пластик, гума, упаковки і їм подібне. Також, ця піч є прикладом застосування піролізної технології, що є базою для подальших досліджень, присвячених створенню піролізних печей, а також печей для доспалювання сміття та газу.

Ключові слова: утилізація сміття, піч, піролізний газ, РДФ, горючі матеріали

Ободовський Іван Ігорович – аспірант, Національний технічний університет України “КПІ ім. І.І. Сікорського”, Київ, Україна; ivan.obodovsky@gmail.com, https://orcid.org/0000-0002-1102-7909.

Морозов Вячеслав Сергійович – аспірант, Національний технічний університет України “КПІ ім. І.І. Сікорського”, Київ, Україна; morozov09@ukr.net, https://orcid.org/0000-0002-9200-7028.