Fuel combustion and optimum use of heat energy

Industrialization of stoves

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During combustion or heating the combustible part of fuel is subdivided into volatile part and solid residue. The volatile part consists of **carbon and hydrogen**. The solid residue consists mainly of **carbon**. Combustion represents a chemical reaction, during which from certain matters other simple matters are produced, this is a combination of inflammable matter with oxygen of the air accompanied by heat release. When the temperature in the firebox reaches **300-350 °C, hydrogen ignites and starts burning.** During heating it evaporates together with a part of carbon in the form of combustible gases - **hydrocarbons.** During combustion process hydrogen turns into **water vapours**. **But carbon is not burning yet as it ignites only at 700 °C**. Therefore thick black smoke is exhausted from the chimney. It happens until the temperature in the firebox reaches 700°C in every point. At this moment the combustion of carbon (soot) takes place, the smoke in the chimney is becoming not so dark and gradually disappears. **However at such temperature the combustion process goes slowly and roughly. A certain part of combustible gases doesn't combust completely. In order to ensure effective combustion the temperature in the firebox shall be 900 ° C for wood and 1000° C – for coal.**

In case of proper combustion organization combustion reaction product is carbon dioxide from carbon combustion, water vapour from hydrogen combustion, nitrogen as a component part of air needed for combustion, and this is 4/5 of its volume. Actually due to unequal mixing of hydrocarbon with air the latter has to be supplied in amount by 1,6-2,4 times more then theoretically calculated. Therefore there is a surplus of air in the firebox that didn't take part in the combustion process and also water vapours from water evaporation that is normally present in fuel. **All these gases are called ballast gases, they do not take part in combustion but only get heated due to the heat extracted from combustion of carbon and hydrogen, in other words, they take off useful heat.**

The molecules of all the above-mentioned gases move in any direction, they are not coupled with each other.

It is possible to reach an effective combustion process and obtain maximum energy but at the same time use this heat inefficiently. On the contrary, it is possible to extract energy contained in the fuel completely but use it effectively. Therefore it is possible to consider that the efficiency of the stove is made up from **efficiency of energy extraction** from the fuel and the **efficiency of heat usage**. **The combustion efficiency characterizes the part (%) from the total energy resource of wood that can be transferred into heat during fuel combustion**. The question arises, in which system? **If fuel combustion takes place in the bell more energy is extracted and used than in the system of forced gas movement due to a lesser influence of ballast gases**.

In order to improve the efficiency of heat extraction (i.e. combust fuel more efficiently) it is necessary **to increase temperature in the firebox and reduce the influence of ballast gases on the combustion process.** The stoves operating on the principle of forced gas movement, including the principle of counterflow have been built for more than 100 years. At present their design hasn't practically changed. The activity of designers was aimed at **optimization of primary and secondary air supply and at reduction of the amount of water**

in the fuel, at combination of various fireplaces in the units, at improvement of various parts of stoves. In order to ensure efficient combustion it is necessary to supply the amount of secondary air in much greater amount than is required theoretically so that the harmful carbon monoxide (the product of incomplete combustion) reacted with the oxygen in the air and turned it into carbon dioxide. It is important to ensure its adequate mixing with oxygen contained in the air in the firebox volume, so that all the gases coming out from the firebox react with the air. Otherwise we will have a case of "dirty" combustion. However in this case the amount of ballast gases passing through convective system of the furnace increases, which leads to reduction of its efficiency. **During the latest years the design of furnaces with forced gas movement has reached the highest possible level and there's practically no possibility to improve their efficiency any longer.**

At present all stoves all over the world are built on the principle of **forced gas movement.** Heat accumulating furnaces are basically designed using the principle of counterflow. In boilers pipes or tanks for heat-carrying agent are located in the firebox. Heating furnaces are also being built with the use of metal firebox inserts functioning on the principle of smoldering combustion or gas-generator boilers and furnaces, in which the firebox walls are **heat-extracting surfaces**. In all these stoves all the gases that are formed as a result of combustion reaction, including **ballast gases pass through the convective system.** The ballast gases cool it thus reducing the efficiency of the stove. The fuel energy, that is heat received from combustion of carbon and hydrogen, is not used completely but is reduced due to ballast gas heating. **The following conclusion can be drawn: in order to increase efficiency of the stove it is necessary to reduce the influence of ballast gases on the combustion process.**

In stoves with forced gas movement there is no place for proper placement of boiler heating element (heat exchanger) so that the conditions of fuel combustion corresponded to the conditions of extracted heat. **If boiler heat exchangers are placed inside the firebox, the temperature in it goes down, in other words the conditions for fuel combustion worsen. In case of increase of channel dimensions with the purpose of fitting heat exchanger in, the energy of the gas flow is diluted and the temperature in the flow decreases.**

Besides the efficiency of firebox inserts and boilers depends on the speed and heat exchange value through the walls of the firebox and the walls of water heat exchanger. **The conditions of fuel combustion come into conflict with the heat exchange conditions. So the more heat we take (that is the more we increase heat emission efficiency) the more we worsen the conditions of fuel combustion that is reduce the efficiency ratio of energy extraction contained in the fuel.** Heat exchangers that are placed inside the firebox (cold core) decrease the temperature inside, thus worsening the conditions of fuel combustion.

The combustion of fuel and heat exchange in heat generators built in the system of free gas movement in accordance with the formula: " **The stove's lower level and the firebox are combined to form a single space creating a lower bell**" is quite different. This formula foresees availability of a dry joint (a 3 cm crevice) between the fireplace and the bell. The firebox may be different both with regard to its design and principle of fuel combustion. This can be the principle of the upper combustion, the principle of the lower combustion, the principle of return combustion, and the principle of gas generation, etc. Any type of fuel can be used for combustion. **The gist of the formula. We speak about fuel combustion in the firebox located in the bell and optimum use of extracted heat energy. The main point of the conception is to obtain maximum heat during fuel combustion; the heat obtained shall be used in maximum volume; the design of heat generator shall meet functional requirements and ensure optimum heat emission.**

One of the remarkable features of the bell shall be pointed out: "If hot gases are transferred through the lower zone of the bell, the latter will accumulate their heat and irradiates it through the walls or heat exchanger placed inside the bell". That is when

passing through the bell the gas flow is distributed in accordance with the temperature of gas components incorporated in the gas flow.

In firebox of multilayer type (the principle of the upper combustion), see diagram, Fig. 1, the solid fuel layer is to a greater extent the zone of fuel gasification, from which gaseous products of gasification mixed with ballast gases come into the firebox volume. In this area a certain part of cold ballast gases being the coldest and the heaviest penetrate through the crevice into the lower part of the first bell. **The combustion zone to a greater extent is located above the layer in the firebox volume where combustion of exhaust gases takes place due to supply of secondary air into this area. To improve gasification of fuel the supply of primary air shall be limited (heating with a limited amount of air), especially in cases when large amount of glowing coal still remains in the firebox.**

High-temperature combustion process is possible only at ensuring of fuel gasification that can be achieved only by increasing temperature in the firebox and creating oxygen-containing medium. From the other side, only high-temperature heat is capable of quick heating of all gasifying fuel to activate gasification process.

High-temperature combustion process is also possible in case of absence of cold core and separation of flows of cold and hot gases. Another source of temperature increase in the firebox may be regeneration (that is using heat of exhaust gases to heat air needed for combustion process).

In heat generators built in accordance with the above-mentioned formula all the conditions of complete fuel combustion are easily realized: the supply of the optimum amount of primary and secondary air; good mixing of air with the fuel; high temperature inside the firebox; proper design of the firebox (the combustion finishes in the firebox space, not higher than the catalyst and not further than the dry joint). Non-observance of at least one condition in full will lead to incomplete combustion of fuel. These conditions are maintained due to distribution of hot and cold gases; the absence of cold core in the firebox reducing the temperature inside it; regeneration (using heat of exhaust gases to heat air needed for combustion process); using of combustion catalyst, etc.

One of the main tasks is the supply of secondary air. The best way to supply it from the ash-pit using two ways: the first one - through the crevice at the firebox door-5; the second one - under the catalyst or via catalyst as well as a small amount into the dry joint. Using the first way, the secondary air due to chimney draft passes over the fuel layer (being cold) into dry joint, ensuring oxidation of hydrocarbons. Part of excess air and ballast gases that haven't taken part in the reaction are discharged at the lower part of the bell. In this case turbulence of the flow is ensured as during combustion hot gases comprising the flow go upward. Using the second way, the air passes through the chamber of the firebox wall-8 under the catalyst or into the catalyst and also into dry joint through crevice-9, being heated on the way. The combustion catalyst ensures turbulence of movement of the outlet flow and high temperature, which is especially important in the end zones of combustion where the concentration of fuel and oxidant is low; they are separated by the combustion product making their interaction difficult. In other words it ensures complete combustion. The same can be said about the gas flow passing through the dry joint, where it gets oxidized.

The amount of secondary excess air doesn't make a large impact on the decrease of the stove efficiency.

When combustion of fuel takes place in the firebox placed in the bell the degree of energy extraction from the fuel increases. The ballast gases being cold and heavy cannot go up, and through dry joint and the lower part of the bell they are transferred to the secondary bell for further use. The largest part of fuel energy is sent to the first bell to be used. In the bell the energy is concentrated irrespective of its dimensions and is kept there until the temperature inside it is at least a little bit higher than the temperature of exhaust gases from the bell, that is until it is absorbed by the heat exchanger.

The conditions of the optimum use of the exhaust energy are also well realized, also due to the use of the “double-bell” system. The system is very flexible, it provides a possibility to design a great many stoves of various purposes and kinds. The bell may have any form and volume. A boiler, a heat exchanger, a steam generator, a retort, and a heat-accumulating device ensuring heat emission within 24 hours and other equipment maybe installed inside it. **Unlike the system with forced gas movement, our system is provided with the fuel combustion conditions corresponding to the conditions of the heat exchange, that is during increase of stove heat emission the combustion conditions won’t change.**

On the basis of this theory new design principles have been developed for the **charcoal burning units and a gas-generator boiler. They ensure complete control of pyrolysis process at every process stage as well as during preparation of initial raw material.**

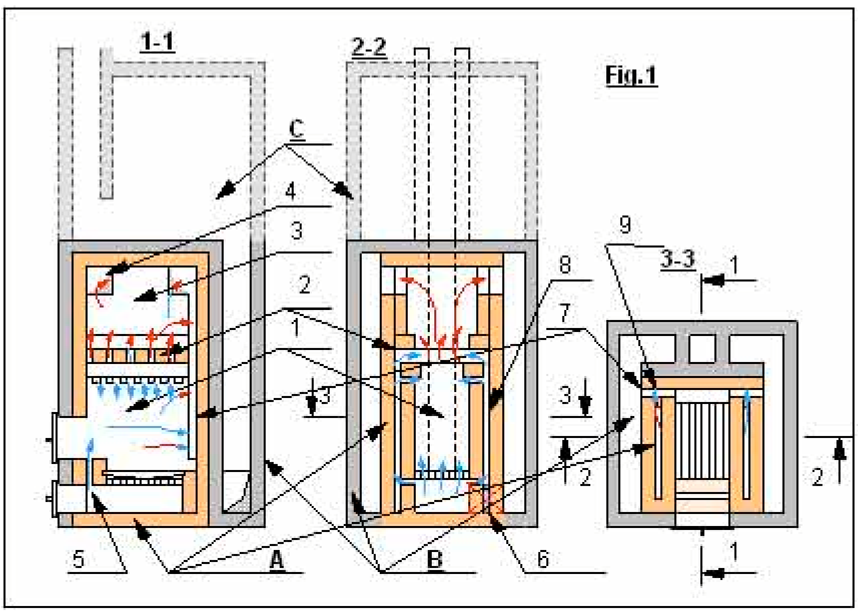

Fig.1 features a diagram of a furnace built in accordance with the formula: ” **The stove’s lower level and the firebox are combined to form a single space creating a lower bell**”. The following designation is used on the diagram. A, B and C are the firebox, the lower bell (the first one) and the upper bell (or the second one in succession) respectively. Heat exchangers, for example, boiler heaters can be fitted into the lower bell B.

The firebox consists of an ash-pit with a fire-bar over it, combustion space-1, catalyst-2, and space over the catalyst-3, the upper part of which is provided with the lower bell outlet holes. In the front part of the firebox there is crevice –5 for supply of secondary air from the ash-pit. Regenerator –6 can be fitted in the lower part of the sidewall. The rear part of the firebox is provided with a dry joint (a 3-cm wide crevice). The sidewalls of the firebox are provided with chamber–8 through which secondary air is transferred from the ash-pit via openings under the fire-bar under the catalyst or inside it. The rear part of the chamber is provided with crevice –9 of 5 mm in width for supply of the secondary air into the dry joint.

Baking chamber of baking oven may be inserted into the space over catalyst-3, a steam generator (in steam sauna furnace) and other equipment. The firebox in the diagram is shown with symmetrical outlets into symmetrical bell. The firebox may have an asymmetrical form and have outlets into an asymmetrical bell. This makes it possible to unify the firebox for various models of various purpose stoves and create modular stoves of factory manufacture.

The bells may have any form and can be built of different kinds of materials. In accordance with the customer’s request different stove equipment can be fitted inside them.

It is possible to create firebox made of heat-resistant concrete of factory manufacture. One and the same firebox can be used in stoves of various kinds. This can be a baking stove, a stove for steam sauna, a heating boiler, a multilayer stove, a combined stove with various functions, etc. For example, if we take firebox **A** and insert it into bell **B** shown in Fig.1, we can obtain the following stoves that are also capable of operation using electricity:

1. A heating stove with a single layer bell, similar to counterflow stove but more efficient;

2. A water boiler, if we insert heating elements into the side chambers of the bell:

3. A baking oven, if we insert a cooking chamber over the catalyst in space –3;

4. A stove for steam sauna if we insert a steam generator over the catalyst in space –3;

5.A heating stove with an increased thermal capacity for severe climatic conditions if we make an external containment (it is possible to be done by the customer).

We can build-in another bell close-by or above, which will increase the stove efficiency. At the same time they may perform different functions. Firebox **A** may be inserted into the bell having a great many specific solutions, also including version of an open fireplace.

At the beginning one type of firebox can be manufactured at the manufacturing works. The bells can be made of precast elements making it possible to build various types of individual stoves with this firebox in accordance with the customer's request. After a certain period of time it is possible to continue manufacturing fireboxes of another type and power with regard to our system.

Such multifunctionality of our "system" assumes high competiveness on the stove market. We consider this trend of stoves development quite promising, meeting the requirements of energy saving and market demands.

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