Solution of Some Problems which can Occur at Production and Combustion of Straw Pellets and Pellets Made of Agricultural Wastes

Isemin R., Konyakhin V., Kuzmin S., Zorin A., Mikchalev A., Viryasov D.
Tambov State Technical University
392000, Russia, Tambov, Sovetskaya st. 106

The problems of the use of straw and other agricultural wastes as fuel taking into account the peculiarities of Russia are divided into three groups: 1) the problems connected with straw provision and storage, 2) the problems of straw densification, 3) the problems of combustion of straw pellets and pellets made of other agricultural wastes. The solution of the problems mentioned above is given. The authors' existing experience of the construction of plants for the production of straw pellets is described. A new technology of combustion of pellets made of agricultural wastes in a fluidized bed formed by pellets alone and solid products of their combustion is suggested

1. Introduction

Remaining high prices for conventional energy products and ecological requirement enforcement to electric power plants determine the interest to the use of a biomass as fuel. Biomass resources across Russia are located extremely spotty, moreover the basic stocks are concentrated in the northern and eastern regions with the lowest population density and, accordingly, with smaller requirements for thermal energy than in the central and southern regions. However, just these regions have the greatest resources of straw which can be used for thermal energy development. During the 2001-2007 period the average crop of winter wheat was 25 million tons, the average crop of winter barley was 1,9 million tons, the average crop of rye was 4,5 million tons, and at the same time the average crop of straw in Russia for a year was about 38 million tons.

The scientific and educational centre of the Tambov State Technical University has a task to create the first in Russia demonstration plant for the production of densified fuel of straw and a task to produce thermal energy of this fuel. This demonstration plant has been created in Zavetinsky district of Rostov region. The agriculture of this district is connected with sheep breeding and cultivation of grain crops. Winter crops occupied 34568 hectares in 2008. The croppage of straw of winter crops was 56 thousand tons in 2008 and on average it was 46,7 thousand tons a year during the 2000-2008 period. On the average about 28 thousand tons of straw of winter crops remained non-demanded and was burnt on the fields annually for the period from 2000 to 2008. In this district the heat supply is carried out by means of the combustion of low grade anthracite (the heating value is about 18,8 MJ/kg) in 22 boiler-houses with capacities from 200 to 400 kW. 3000 tons of coal is burnt in boiler-houses during a year. 3600 tons of straw is required for coal replacement.

During the creation of the demonstration plant the following problems have been revealed which can be divided into three groups: 1) the problems connected with straw provision and storage for the following use as fuel, 2) the problems of straw densification, 3) the problems of combustion of straw pellets and pellets made of other agricultural wastes.

2. Problems connected with straw provision and storage for the following use as fuel and their solution

The elemental composition (Khor et al., 2007) and heating value of straw do not much differ from the corresponding values of wood, though the heating value of straw is lower than the heating value of dry wood. But straw has low bulk density (about 40 kg/m^3) therefore it is very difficult to transport straw in its initial condition from a place of gathering to a place of combustion and to store it near to boiler plants. Densification of straw in bales makes the density rather higher (theoretically up to 150-180 kg/m^3). The baler PR - F – 145 made in Russia is used for the densification of straw in bales of the diameter of 1,45 m and length of 1,4 m. The density of a straw bale is 88 kg/m^3. The reasons of low density of a bale are short stems of straw (120-150 mm) and low moisture of straw (4-7 %). The low density of straw bales makes impossible in our project the use of boilers for combustion of straw in the form of bales or in a shredded kind (with shredding of bales directly in a boiler plant). Therefore it has been decided to produce straw in bales into pellets.

3. Solution of the problems connected with production of straw pellets

The plant was designed for the production of straw pellets. Its scheme is shown in figure 1. The redesigned press OGM 1,5 made by Joint stock company «Radviliskis machine factory» (Lithuania) was applied in the plant. The matrix with dies with the diameter of 7 mm and length of 57 mm each was used for the producing of straw pellets. The choice of the very matrix was conditioned by the following circumstances. It was established that for the production of high-quality pellets it was necessary that the grate with the diameter of apertures equal to half of the diameter of dies of the press matrixes was installed on a shredder of the second stage. On the other hand the thinner was the shredding, the less was the wear of a press. However, the increase of grading fineness sharply reduced the efficiency of a unit ‘a primary shredder – a secondary shredder’. So, at the use of the grading screen with the apertures of 4 mm (the diameter of produced pellets should be 8 mm) on the secondary shredder the efficiency of the plant was 400 kg/hour, with the apertures of 5 mm (the diameter of pellets is 10 mm) – 700 kg/hour, with the apertures of 6 mm (the diameter of pellets is 12 mm) – 1200 kg/hour. During pressing of straw with the moisture of 12 – 14 % on the press OGM – 1,5 there was the maximum efficiency equal to 2,5 tons pellet/hour. In order to gain the reasonable efficiency of the whole plant with the same high quality of pellets it was decided to install the grate with the diameter of the apertures of 7 mm on a secondary shredder. Thus obtained pellets were of sufficient durability (taking into account that it was necessary to transport them on the distance up to 60 km) with the length from 10 to 35 mm.

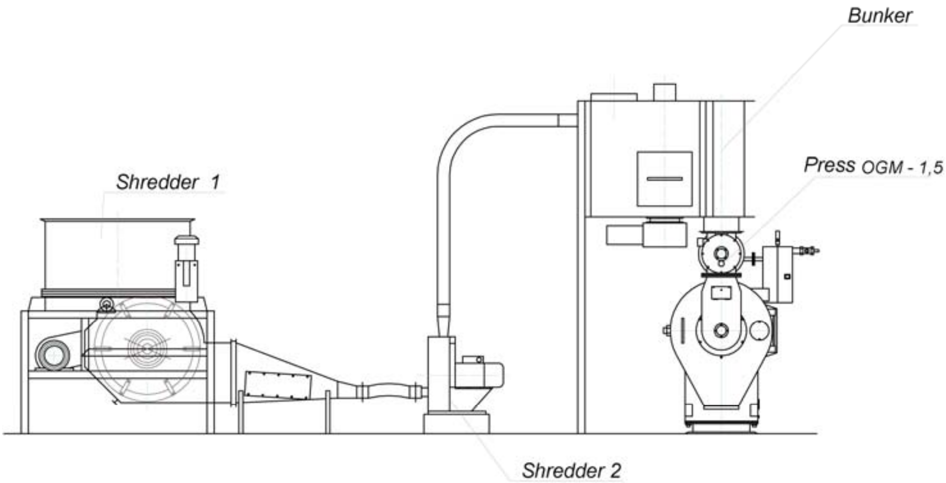

Figure 1. Scheme for the production of straw pellets.

It is necessary to mention that for the primary shredding of straw it was impossible to use shredders of known designs, including the shredder IRK – 145 which was widely used in Russia. After that shredder the size of chips of straw on the average was equal to 100 – 150 mm. Such straw was difficult to transport to a secondary shredder and the efficiency of the whole plant was very low. Later a principally new shredder IRR – 1was designed (fig.1). The efficiency of this shredder could be regulated in a wide range without loss in quality of shredding. The size of the obtained chips of straw after a primary shredder did not exceed 25 mm. However, even by means of the shredder IRR – 1 it was not possible to increase the efficiency of the whole plant to the maximum efficiency of the press (2,5 tons pellets/hour).The reason of it was again low density of straw bales. To avoid the destruction of these bales they were corded up and manual removal of the cord took 4 – 5 minutes that reduced the efficiency of the plant as a whole

4. Solution of the problems connected with combustion of straw pellets and pellets made of other agricultural wastes

In the process of combustion of straw and similar to it agricultural wastes the following problems can occur: the combustion rate of these wastes in combustion plants of known designs is much lower than the combustion rate of wood; fixed carbon, contained in fuel, practically don’t burn up and it increases the fuel loss due to mechanical incompleteness of combustion; low melting point of ash leads to slag agglomeration in a boiler furnace which obstructs the normal work of a boiler (Khor et al., 2007, Rőnnbäck et al., 2009, Kiesewalter and Rőhricht, 2004).

We have developed the technology of combustion of pellets of straw, millet husk, rice and similar wastes in a fluidized bed which is formed by pellets alone and solid products of their combustion (their char particles and ash), and we have also designed a boiler where this technology is applied. During combustion in such a bed the ash formed at combustion of pellets is constantly crushed by heavy pellets which are constantly entering the bed. Small particles of ash are taken out of the bed because of high gas velocity in the bed which is necessary for maintaining heavy granules in a suspension state. It prevents the accumulation of potassium compounds in the bed (the accumulation of potassium compounds in the bed is the main reason of ash and slag agglomeration). Moreover even if such agglomerates are formed, they are crushed at once by constantly moving heavy pellets.

The experiments on combustion of four types of pellets (straw pellets, sunflower, millet husk pellets, and rice pellets) were carried out in the experimental plant, which was a fire tube of a boiler with a furnace with a fluidized bed in the bottom part of a boiler. A grill with 5 % fraction of an open area was placed on the bottom of a fire tube. The diameter of the fire tube of the experimental plant was 1000 mm, the length was 600 mm. In the course of the experiments, a fresh pellet portion with the weight of 4,2 kg was fed intermittently on the bed of the hot ash remained from the combustion of the previous portion of pellets of the same type. Then a forced draft fan was turned on and the portion of pellets ignited. At the same time the temperature of gases over the bed of the combusting fuel was measured every second by a Ni/Cr thermocouple of type (K) connected to the device «Center – 306» and to the computer. The air flow rate on the outlet of a forced draft fan was measured by a heat-loss anemometer and was measured within the range from 0,25 to 0,53 kg/s. After the ending of the combustion of each portion of fuel, the sample was taken out of the furnace and exposed to the analysis for the identification of char content. The duration of combustion of a pellet portion depends on the consumption of the air fed for combustion. With the increase of the gas velocity in 3,85 times the duration of combustion of a wood pellet portion decreases 2,61 times.

The duration of combustion of a straw pellet (figure 2 c,d) portion at this air flow rate is 133,8 s. At the air flow rate of 0,25 kg/s the duration of combustion of a portion of fuel is 71,3 s. The combustion rate of straw pellets in a fluidized bed is almost equal to the combustion rate of wood pellets in the same bed (figure 2 a, b). The recalculation of the experimental data presented in the work (Khor et al., 2007) has shown that the portion of cut straw in a dense bed would combust at least 500 s and it is 3,74 – 7,01 times more than the duration of straw pellet combustion in a fluidized bed.

The duration of combustion of the same portions of millet husk pellets (figure 2 e, f) and wood pellets in a fluidized bed is similar, though millet husk pellets contain 19,4 times more ash than wood pellets.

Our investigations have shown that during combustion of agropellets in a fluidized bed of pellets alone, their char particles and ash the temperature rises up to 1000-1100 °C and that is enough for ignition and stable combustion of char particles; moving particles are constantly destroying ash and slag agglomerates formed in a bed, hence the furnace refuse has a powder-like structure.

Therefore, during the combustion of the granules of straw on the suggested way the loss from mechanical incompleteness of combustion is 7,94 %, while the loss from mechanical incompleteness of combustion in a usual pellet boiler «Pelling-27» (Czechia) in a dense bed of moving granules is 36,44 %; the losses from mechanical incompleteness of combustion of millet husk granules are 15,76 % and 30,12 %, of rice

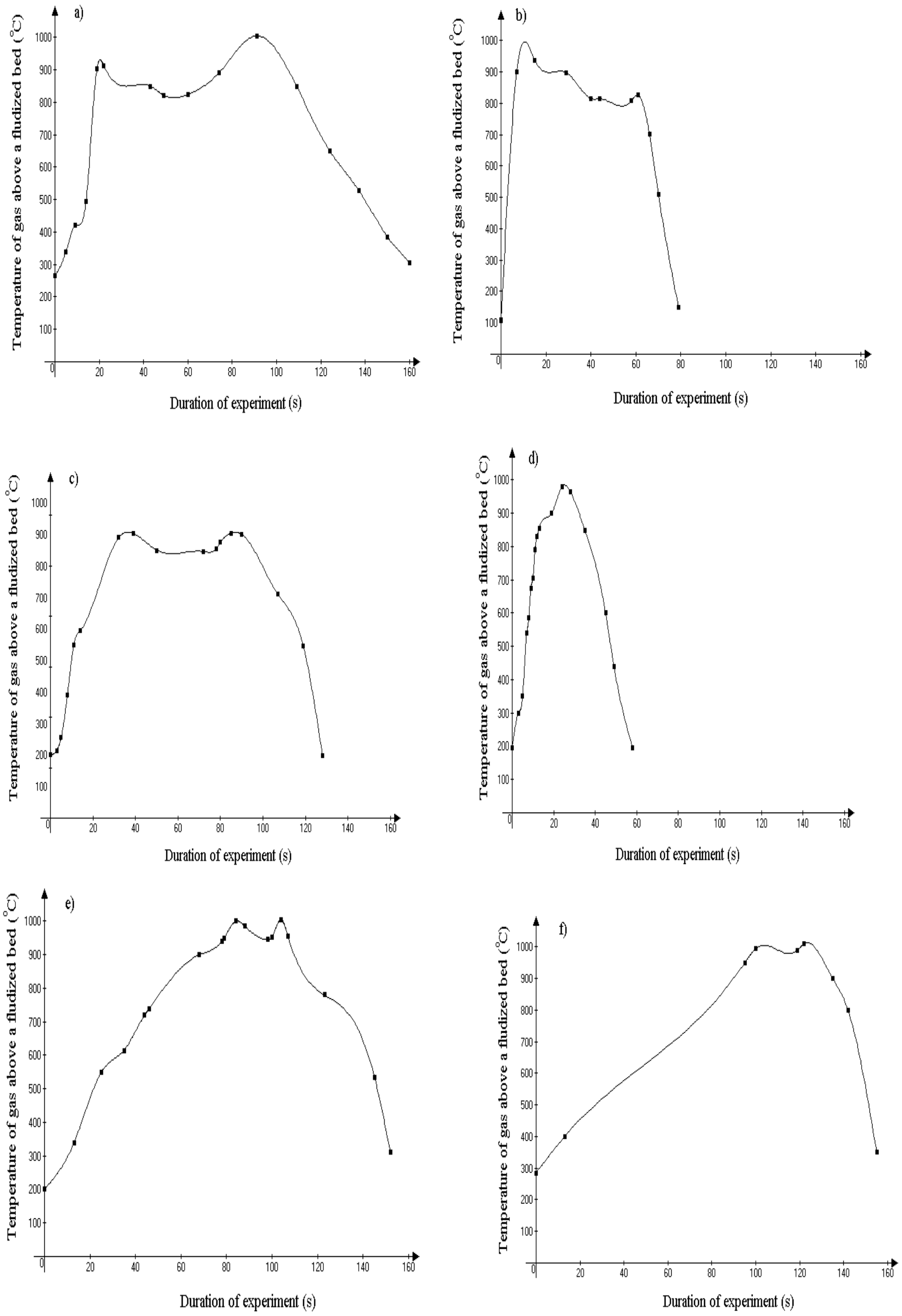

Figure 2. Gases temperature curve over a bed of combusting pellets (a, b – wood pellets 1, a – mass flow rate of air is 0.25 kg/s, b – mass flow rate of air is 0.53 kg/s; c,d – straw pellets, c – mass flow rate of air is 0.25 kg/s, d – mass flow rate of air is 0.53 kg/s; e, f – agropellets of millet husk, e – mass flow rate of air is 0.25 kg/s, f – mass flow rate of air is 0,53 kg/s).

husk granules are 10,07 % and 43,02 %, of sunflower husk granules are 4,96 % and 12,46 % respectively.

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