Comminution of forest biomass by modified beater wheel mill in a power plant

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Abstract

Today, the renewable energy sources – e.g. forest biomass - have great importance, not only domestic but industrial – f.i. power station - utilization can be seen as well. However, the comminution of such fibrous texture materials requires relatively high energy and special grinding stress. In the thermal power station of AES Co. Ltd. Berente mainly wood biomass is burned as fuel. The size reduction of biomass is achieved by beater wheel mills, which were designed originally for coal. The aim of the accomplished research carried out by the University of Miskolc and the power station was the increase of the capacity of the fuel supplying system. Systematic industrial and laboratory experimental series were carried out by changing the mill feed and results and conclusion are presented in this study. During the on-site industrial tests four fuel supplying systems (beater wheel mill, air classifier, heat exchanger, pipes) were equipped with a complete data acquisition system containing different sensors. Three sampling point were built 1) from the feed, 2) from the rejected coarse material after the air classifier and 3) from the final product (isokinetic) from the pneumatic transport pipe. Results are presented in the study.

Keywords: biomass comminution, beater wheel mill, mill – classifier cycle, sampling.

1. Introduction

The protection of the environment and economical operation at the same time, this is a real challenge for companies providing power by burning fossil fuels at these days. The trade of CO_2 quota and present legislation had led the thermal power station of AES Co. Ltd. Berente, Hungary to change their fuel into wood biomass from coal. Their original technology was designed for coal and beater wheel mills were applied to comminute the raw fuel and supply the furnaces. This technology is widely applied in coal power plants. Because the remaining lifetime of the Berente Power Station high cost investment was out of the question, but the increase of their capacity and efficiency by low cost modifications was their evident interest. Therefore, the University of Miskolc and the AES Co. Ltd. Berente, have carried out an about one year long on-site and laboratory research by with the capacity was significantly increased. This paper reports about results of this research.

2. Background

2.1 The fuel supplying system by a beater wheel mill

The circulated flue gas of a wood biomass furnace is used to transport the fuel. Flue gas is discharged from the furnace from a not too hot spot (700 °C), then the pre-chopped (< 30 mm) wood transported by a belt conveyor is fed into the flue gas pipe through a simple hole or through a lamella feeder. Afterwards, a heat exchanger considerably decrease the flue gas temperature, the flue gas with the fed chopped wood gets into the beater wheel mill horizontally, after a 45 ° pipe section at about 160 °C temperature.

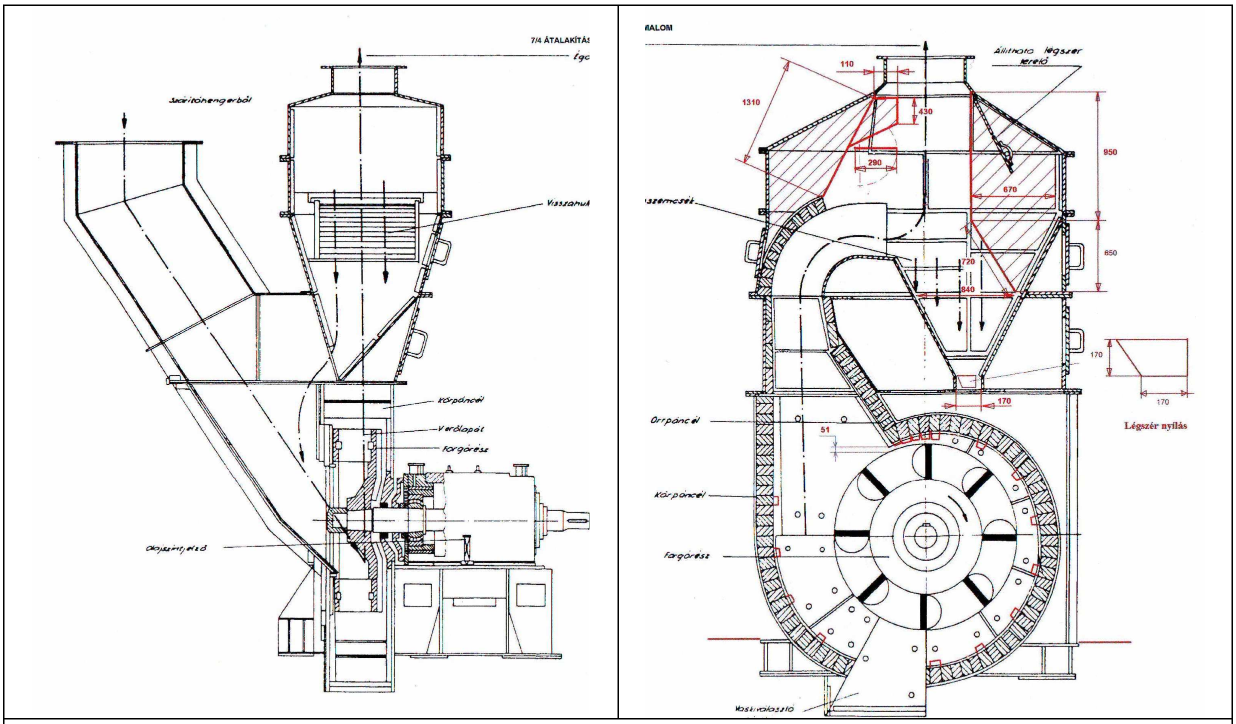

Figure 1. The beater wheel mill and air classifier.

The beater wheel mill has two basic roles; it is a ventilator and a mill at the same time. This is a considerable disadvantage of this technology, because the two functions cannot be controlled separately, but just one machine is necessary. The mill is a beating – impacting (prall – hammer) type of mill. Comminution mainly takes place by impacting (it was good for coals) and by beating in smaller extent. The original armor of the mill was modified for wood comminution; ribs were built to improve the shearing effect. The mill and the air classifier (Figure 1.) work together in a milling cycle. The product of the mill – classifier cycle is transported by the flue gas, through a heat isolated pipe into the burner in the furnace. One furnace is supplied by four fuel preparing systems, each with a beater wheel mill and a burner. The technology is equipped with a computer control and regulation system. Each fuel supplying system of a furnace is monitored by different transducers; the following parameters are measured on-line: mass flow rate of the feed, electrical current of the driving motor, temperatures before and after the mill – classifier cycle. Many more parameters are monitored, but those four + the moisture content of feed measured by sampling periodically are important for the regulation of the fuel supply. If the current increases into dangerous levels; system reduces the feed mass flow, this is the basic principle of regulation.

2.1 Characteristics of a mill – classifier cycle.

The schematic principle of a closed mill – classifier cycle is shown in Figure 2.

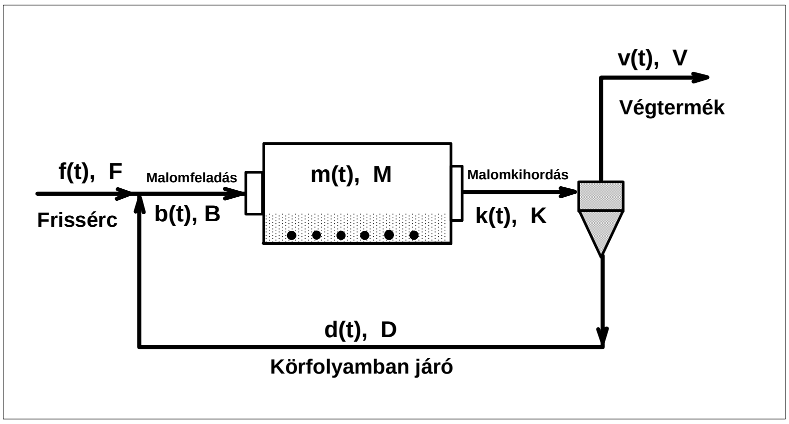

Figure 2. Instant and balanced material flows of a mill – classifier cycle.

If the system is balanced the following equations can be written based on the law of conservation of mass:

$$\mathbf{F = V}$$
$$\mathbf{B = K = F + D = V + D}$$

Where, F = f(t → ∞), V = v(t → ∞), B = b(t → ∞), K = k(t → ∞), D = d(t → ∞) and M = m(t → ∞) are balanced mass flow rates.

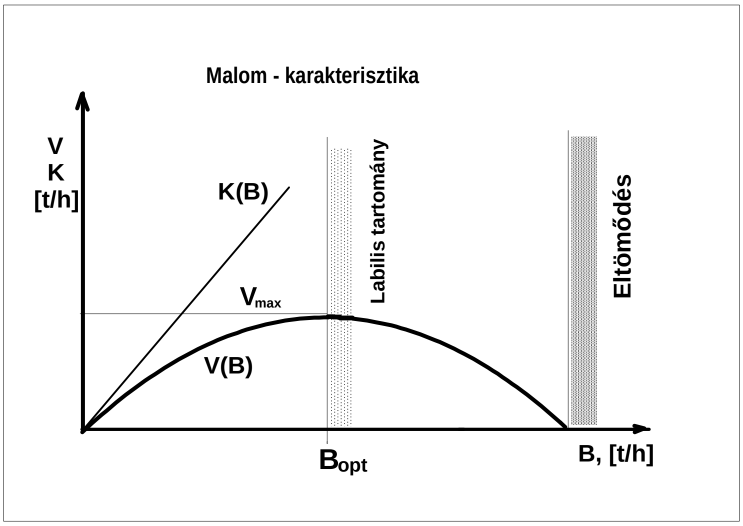

Figure 3. Characteristic of mill – classifier cycle (Mill characteristic)

If B mill feed is increased, than up to a limit value the V capacity of the milling system increases as well, because the quantity of material in the mill increases. At B_{opt} optimal charge the mass flow rate of final product reaches the V_{max} value, and in this point

D(B) = K(B) - V(B), therefore D_{opt} is the mass flow rate of the cycling material. If the mill feed is higher then the optimal B_{opt} the mill gets into an unstable range, the V mass flow rate of final product and the milling speed decrease, the milling fineness of mill output, the quantity of D recycling material and B mill feed drastically increase and finally mill plug happens. This short explanation illustrates how important the proper mill – classifier regulation is.

3. Experimentation

3.1 The data acquisition and sampling system

The built control and regulation system of a fuel supplying unit is suitable for the daily operation, but not sufficient if we want to find the way to improve the mill performance. Therefore, complete fluid mechanics data acquisition- and chopped wood sampling systems were installed into each of the four fuel supplying systems, one after one. For the determination of the comminution ratio and other data necessary to evaluate the mill performance, samples from different places had to be taken. The whole cross section of fresh wood feed was sampled at the feeder. After the feeder, a belt conveyor transports the chopped wood and some percent of coal into the flue gas pipe. A specially designed sampling vessel was built, by with the whole cross section of the material falling down from the belt conveyor was sampled. This sample represents the input of the mill because the heat exchanger does not influence the particle size structure of the material. The next stage of the technology, - after the mill - is the classifier. In Figure 1, the point of feedback can be well seen, where the coarser particles go back to the mill. A window on the mill, and an adequate shaped sampling vessel was built by with the whole cross section of the back fed material was sampled. The most difficult sampling task was to solve representative sampling from the product of the mill – classifier cycle. The output of the classifier goes up to a vertical 450 mm diameter pipe section that is connected later into the burner but at a height about 20 m higher. Sample must had to be taken from this vertical pipe section. For this reason an isokinetic (the velocity of sampling equals to the velocity of flue gas in the pipe on the same axis) sampling system have been developed.

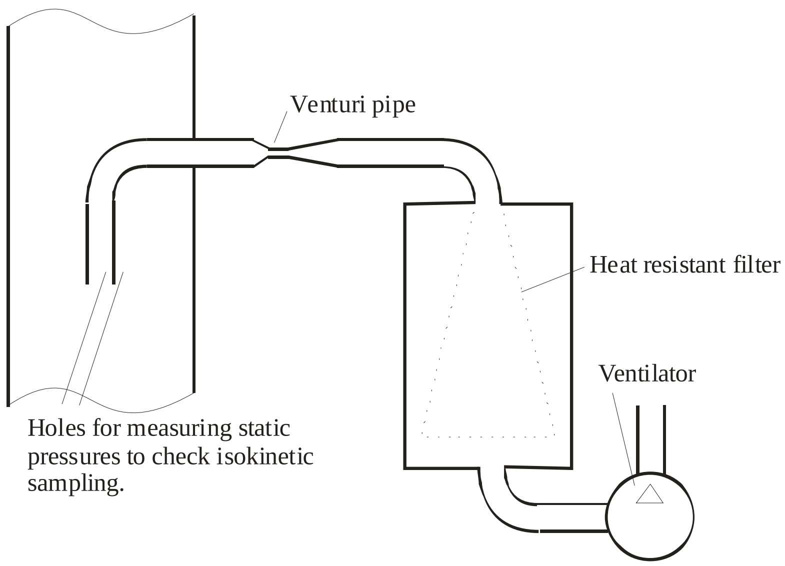

Figure 4. Schematic of the isokinetic sampling system.

On the pipe a Bayonet – joint sampling point was built up. After removing the Bayonet – cover the sampling pipe can be put into the pipe and can be fixed at any position. During this research only the center axis was sampled. The sampling pipe was connected into a Venturi pipe by with the velocity of sampling was measured. The flue gas sample from the sampling pipe was led into a sucked vessel, in which a heat resistant filter was installed. The maximum flue gas temperature, about 160 °C was not a problem, but some smoldering wood pieces burned out the filter, sometimes it had to be changed. The frictional flow loss of the sampling pipe and the bag filter had to be supplied; therefore a ventilator was installed at the end of the system. The motor of it was driven by a frequency converter. In the outer and inner sides of the sampling pipe static pressure sensing holes were made. If the static pressure at a height at the outer side equals the one at the inner side the flow velocities have to be equal as well, because the Bernoulli equation. That means sampling is isokinetic. The revolution number of the ventilator shaft had to be regulated by the way the static pressures should be equal.

Furthermore of fuel sampling, another complete research system, a fluid mechanics computer data acquisition system was temporarily installed. The distribution of static pressure along the fuel supplying system was measured by piezo electric pressure transducers (0 – 2000 Pa range). The static pressure was measured between the mill and the classifier as well by plugging a pipe through the hole of a removed screw on the outer armor of the machine. The velocity profiles of different pipe sections were measured by a Prandtl tube and a hand pressure instrument during static investigation. During dynamic research flow velocities at the center point of different pipe sections were measured by some Prandtl tubes and piezo pressure sensors. The outputs of the amplifiers of different sensors were connected into a computer AD card, the measuring software was written in C++.

3.2 Measurements

To obtain general information about the four fuel supplying systems the investigation started with systematic load tests. It means that after the complete instrumentation of a unit, tests started by setting up a low load (typically 4 t/h) and after the unsteady state, continuous computer monitoring and systematic sampling were performed. Sampling was started from the end (at the isokinetic point, after the classifier) of a line, coming to the beginning (feed) to not disturb the operation. Each sampling was repeated three times to check reproducibility. Later on the lab many samples had to be processed. After the complete measurement of a selected load, it was increased to the next level and tests were accomplished by the same protocol. This procedure was continued until the maximum load (typically 5 … 7,4 t/h depending on the unit and surrounding conditions) was reached, namely the beater wheel mill was plugged.

Load tests of the four units had resulted many data, some observation follows. The design and physical construction of the four units were the same, however, they performed differently. In respect of fluid mechanics, the static pressure distribution along the technology line, flow rate of fuel laden gas (0 … 10 000 m^3/h), fuel concentration (0 … 350 g/m^3) were similar, but milling fineness were more different. Rate of size reduction concerning to 50 % particles was between r_{50} = 2.9 – 4.5, for 80 % particles it was r_{80} = 2.2 – 3.3. Particle size distributions of feed, recycling from classifier and product are shown in Figure 5, of a given working condition and unit:

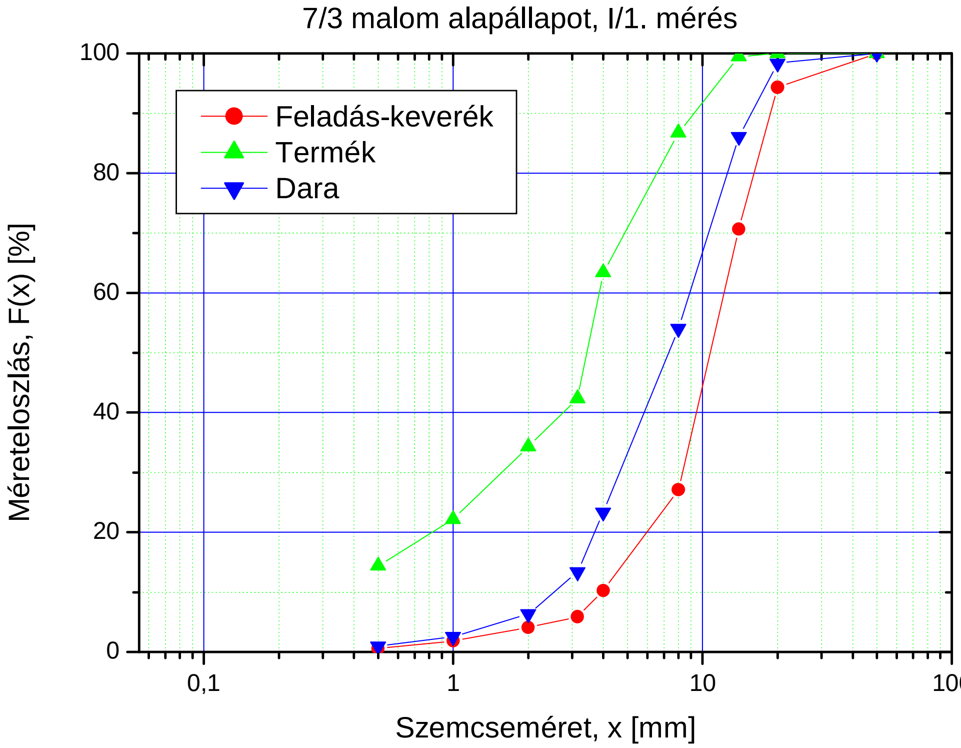

Figure 5. Particle size distributions of feed, recycling from classifier and product of unit 7/3, load 4.2 t/h.

The feed was very even during the load tests, for example moisture content was 35 % with less then 1 % deviation based on 36 analyses. Moisture content of the product in the pipe before the burner was 18 … 21 %. Concerning the particle size structure the aim of the power plant is to comminute the wood fuel below 5 mm; the operation of the furnace was designed for such fuel. It was found that even the feed had already contained about 20 % < 5 mm and the recirculating material from the classifier into mill contained about 30 … 40 %, smaller then 5 mm fraction. Obvious conclusion would be the insertion of a separate classifier to cut fines from the feed and more important this data indicated that the applied classifier did not work properly. Another observation was that with increasing load the particle size structure of product firstly starts to be finer, then after its zenith it becomes more and more coarse.

Supplementing the on site industrial data a laboratory experiment with a hammer mill was carried out to examine the effect of moisture content onto grindability of wood. All other milling parameters were kept constant only moisture content was changed by the way that by drying and wetting different moisture content samples were produced and comminuted in a laboratory hammer mill. As it was expected, 100 % of the completely dried wood sample was milled below 8 mm after 90 s. After 90 s milling, coarse (> 8 mm) fraction was removed and milling was continued in case of wet samples. Even some part of the material of some sample was not able to be recovered completely, because fine wet particles stick onto the machine.

Concluding results of load tests many suggestions were made to the company. In the industry there are beater wheel mills with a separate pre comminution machine, a hammer mill built into the door of the mill. It was also suggested that blades of the ventilator – mill machine should be made from harder material with designed cutting edge. These suggestions were temporarily rejected, but others were realized in one unit first. The aperture of back-flowing material from the classifier into the mill was made bigger. The gap between the revolving blades and the armor of the spiral shape house was made narrower. The structure of the classifier was considerably modified.

After the modifications, newer load and dynamic tests had been carried out to check the effect of changes. During these tests a quite interesting phenomenon was discovered. In the beginning it was mentioned that the regulation strategy of such a feed backed technology is very important. Operators in the control room of the plant set the capacity of fuel supply in accordance of the contracted electrical power. The fuel supply system is operated at safe levels and it means at low levels because sometimes after many hours of stable operation at a given load accidentally mill plug can happen. If the current of the motor increases the control system automatically decreases or ceases the feed. Therefore, dynamic tests had been carried out to examine the system behavior before blockage. Figure 6, shows the main parameters before a point where the automated system stopped the feed because high electric current. At this time fluid mechanics parameters were monitored as well.

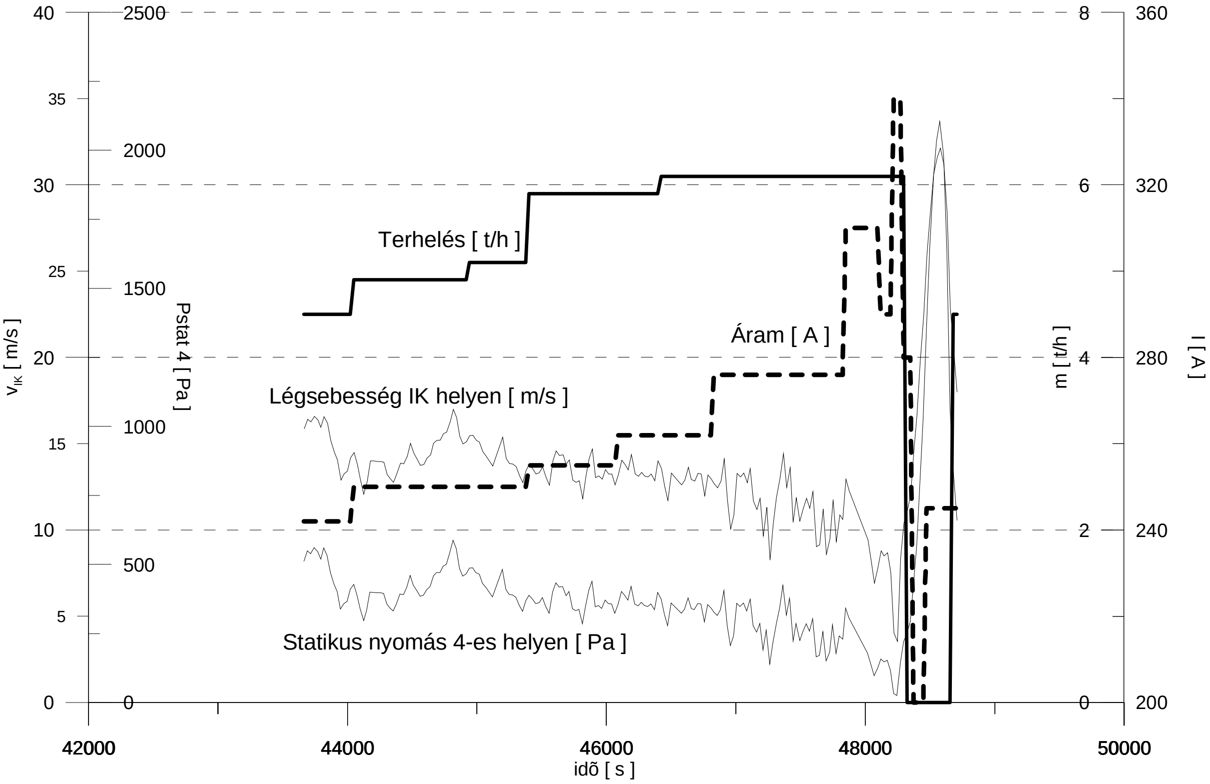

Figure 6. Dynamic examination of a fuel supply system

In Figure 6, parameters are shown as a function of time; the feed is shown by the thick line. Feed was increased gradually and at the point of about 48000 s, current suddenly increased, feed was stopped. The current increase showed the blockage condition at the last moment, but the trend line of fuel laden gas velocity or static pressure at a given position shows it much earlier. Trends of the velocity and static pressure are practically identical. Conclusion of the observed phenomenon is that a control signal should be the easily measurable static pressure and if at a given load the trend of it is decreasing later blockage is expected.

As result of the shortly described modifications at the end of the research capacity has been increased by about 15 % and product fineness has been improved considerably as well.

4. Conclusion

The power station of AES Co. Ltd. Berente, Hungary produces electric and thermal power by burning wood biomass in their furnaces originally designed for coal. The fuel of a furnace is supplied by four processing units each with a beater wheel mill in closed cycle with an air classifier. Aiming at the increase of the capacity, the University of Miskolc and the power plant have carried out an about one year long on-site and laboratory research. During the industrial tests four fuel supplying systems (beater wheel mill, air classifier, heat exchanger, pipes and burner) were equipped with complete data acquisition and sampling systems containing different sensors and specially designed sampling places and devices.

Based on the results of systematic load tests many suggestions have been taken to modify the technology. In the industry there are beater wheel mills with a separate pre comminution machine: a hammer mill built into the door of the mill, the building in of such mill was suggested. It was also suggested that blades of the ventilator – mill machine should be made from harder material with designed cutting edge. These suggestions were temporarily rejected, but others were realized in one unit first. The aperture of back-flowing material from the classifier into the mill was made bigger. The gap between the revolving blades and the armor of the spiral shape house was made narrower. The structure of the classifier was considerably modified.

Experiments with dynamically loading the fuel supply system has resulted a great observation: the trend of the easily measurable static pressure or flow velocity at a given place is suitable to predict the blockage of the system much earlier than the monitoring of the driving motor electric current.

5. References