More than hot air

Wood heating systems are in trend, especially to produce heat and hot water in heat networks. In demand are systems that transform the energy stored in pellets and wood chips in ways that, thanks to optimum combustion, provide maximum heat and pollute the environment with dust and fumes only minimally. A research project at the University of Lucerne aims to develop basic standards so that heating manufacturers can develop optimized designs.

In a research laboratory at the University of Lucerne, scientists study how wood furnaces with high efficiency and low emisssions can be operated. Photo: University of Lucerne

Dr. Benedikt Vogel, commissioned by the Swiss Federal Office of Energy (SFOE)

The Basel based energy company IWB is currently planning to build a second large wood-fired power plant with the capacity to produce 28 MW of power to supply the Basel district heating network. Many other operators of district heating networks in Switzerland use wood as fuel as do industrial enterprises and private individuals. The wood-fuel comes from local forests and enables CO_2-neutral energy production. Despite these advantages of energy from wood, it is not without problems. When wood is burned, particulate matter is produced, which must be removed by electrostatic precipitators from the exhaust air. In addition, waste gases such as nitrogen oxides (NO_x) are released, which can cause respiratory irritation and contribute to acid rain.

Prof. Thomas Nussbaumer at the University of Lucerne, Engineering and Architecture, has worked with his research team for years to reduce the disadvantages of wood-fired heating. As part of this work, the scientists have prepared proposals that may improve

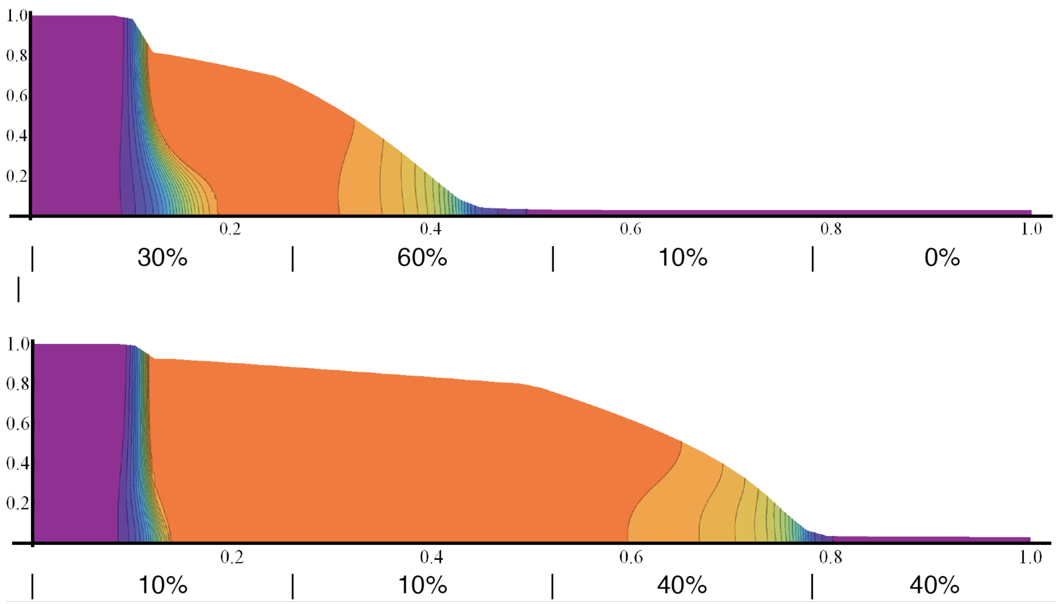
A technical report about the results of a research project in the field of biomass and wood, which is financially supported by the Swiss Federal Office of Energy.

the disposability of fine particulate matter dust separators (or collectors). The current research project focuses on medium sized heating systems on the order of 0.5 MW to 10 MW power capacity. Such heating systems are typically used in local heating networks to supply residential areas and to provide heat to industry, including process heat. Today, the stored energy in wood used in heating systems can be converted with an efficiency of about 90% into heat – if they are operated at full load and are optimally adjusted. "In practice, this value is often not achieved, the actual efficiency is up to 80% and less," says Thomas Nussbaumer.

Effciency loss at partial load

The reason for this loss: Heaters run in spring and fall when the amount of heat required is low. Since the heaters run in turndown, they do not achieve their maximum efficiency. In addition, during the combustion process the furnace is often fed more air than necessary. The result is an excess of hot exhaust gases that escape through the chimney. Due to this excess air some of the energy vanishes unused, which reduces the efficiency. "Our research aims to provide the basics, so wood heating systems operate with an efficiency of 90% when they are operated at a capacity of only 30 or 40%," says Nussbaumer.

With a test system of 150 kW power capacity, scientists at the University of Lucerne study how to optimize the combustion process in a medium-sized wood-fired heating system. Photo: University of Lucerne



The illustration shows how air supply influences the length of the fuel bed: If 90% of the air is supplied to the first two zones (above), the combustion process is faster - only 47% of the grate is covered with wood-fuel. If, in contrast, 80% of the air is supplied to the last two zones, the wood chips begin burning later - the wood fuel now covers 80% of the grate. Illustrations: Kiener / Martinez / Nussbaumer 2014

A look into the combustion chamber of a wood-fired heating system (here in the cold state): The chips are placed into the back of the combustion chamber and are transported via the stepped grate forward and in the process, are thermally decomposed by gasification. Left: initial state of superimposed layers of (colored) chips. Right: the final condition after transport by grate movement. Photos: University of Lucerne

The University of Luzern has at its Horw location, half a dozen schools and laboratory buildings. In section I, the researchers have built a wood-fired heater with a power capacity of 150 kW. With the test system, they have been investigating combustion processes as they occur in mid-sized wood heating systems since early 2014. Laboratory director Dr. Jürgen Good leads visitors to the rear of the system, which fills an entire room. Good points to four pipes that tower up the side of the heating unit. Each of the tubes suck in air, which is advanced by air blowers into the combustion chamber, where in four different zones lie wood chips on a grate. "This is the central innovation of our system," says the ETH trained mechanical engineer, "because traditionally the air is supplied under the grate only in two areas, sometimes in only one. By utilizing four independent grate zones with separately controlled air supply, we can fine tune control of combustion."

Fine control of combustion

The air supply is central to control the combustion process. An air supply that is too large, leads not only to a loss of efficiency, but also to unpleasant build-up of the fuel, which forms deposits in the combustion chamber. In order to achieve optimum combustion, the air supply must be specifically regulated - depending on whether the heating system is operating at full or partial load, whether the grate is covered with woodchips whole or in part, how wet the wood chips are and the amount of energy contained in the particular grade of wood chips.

The Lucerne research project is supported by the Swiss National Science Foundation as part of the National Research Programme 66 "Resource Wood" and co-financed by the Swiss Federal Office of Energy. Results thus far indicate that the fuel conversion and the grate coverage are affected by the air distribution. "By shifting the air towards the first half of the grate, the fuel bed under otherwise identical conditions is shorter, by moving air into the second half of the grate the fuel bed becomes longer," the Lucerne researchers write in an interim report and add: "Although the distribution of air thus stands available as an additionally controllable variable, measurements show that the fuel bed and combustion behavior are more influenced by the grate movement then by the air distribution." From these and other measurement results and simulations, the scientists are drawing up proposals for fine tuning control systems that can help manufacturers to develop efficient and low-emission wood heaters. Whether the proposals can be implemented by industry is largely a question of price. The relatively high price is the reason why wood furnaces with four zones, despite the advantages for small and medium-sized wood-fired systems, are not yet used today.

Cooperation with industrial partners

The Lucerne University collaborates with Schmid energy solutions AG (Eschlikon / TG) on the project, Switzerland's largest manufacturer of wood-fired heating. "The theoretical research findings help us to optimize existing systems and also the design of future systems," says Roland Schmid, head of technology in the Thurgau based family business. Two important points for him are efficiency and emissions: "In terms of combustion efficiency, there is still considerable room for improvement, and the emission of nitrogen oxides is especially relevant for all larger systems, but are also increasingly important for smaller plants with capacities under 2 MW," says Schmid.

Medium sized wood heating systems in the single digit MW range produce today from 150 to 250 mg of NO_x per cubic meter of exhaust. How high the actual value is depends on whether the fuel is pure wood or if residues of bark and needles are burned. Other influential factors include water content and the size of the firewood. In urban and suburban areas, the nitrogen oxide burden is already high, especially due to traffic. The additional emissions by wood heating systems must therefore be reduced to a minimum. Thomas Nussbaumer outlines the goal of his research activities: "Our next goal is to reduce NOx emissions by 40% compared to today."

Develop solutions with foresight

The scientists aim to achieve this goal without the addition of reducing agents, which are used today in waste incineration plants or diesel engines, but rather by appropriate control of the combustion process to ensure that the NO_x formed during pyrolysis in the combustion process itself – is broken down – even before gases combust in the combustion chamber (see text box below). Researchers at the University of Lucerne are developing the fundamentals, which should make it possible in the future to control the wood combustion in such a way so that there are minimal emissions for a wide range of fuel qualities and loads.

The Lucerne project also reflects a reorientation of research in the field of wood-fired heating. For a long time, researchers devoted their attention primarily to the problem of fine particle dust, since the burning of wood causes considerable amounts of fine particulate matter. Since 2007, stricter limits on particulate matter emissions for larger heating systems have been put in place. Through the installation of filters, some of the environmental impact has been mitigated. NO_x emissions, however, have been getting increasing attention. Although the environmental impact of the heating sector lags behind the transport and cement industries, wood heating systems produce more NO_x than gas and oil fueled heating. "I want to pro-actively develop solutions with industry in order to prepare for increased use of wood energy, as has been mapped out in the Energy Strategy of the federal government," says Thomas Nussbaumer.

» For further information on the project, please contact Sandra Hermle (sandra.hermle[at]bfe.admin.ch), director of the SFOE research program biomass and wood.
» More technical papers on research, pilot, demonstration and flagship projects in the field of wood and biomass can be found at: www.bfe.admin.ch/CT/biomasse

Combustion in two stages

As anyone who has a home fireplace knows, putting a log on the fire brings joy as it burns under a comforting crackle. In chemical terms, the combustion process consists of two successive stages: In the first step the flow of air and heat leads to thermal decomposition of the wood, by which so-called pyrolysis gas (consisting of carbon monoxide / CO, methane / CH_4, hydrogen / H_2) and charcoal arises. The pyrolysis gas is burned and then in the second step is again combined with air and burned as a visible gas flame, which sets a chemical reaction (oxidation) in motion that releases energy. Simultaneously, the charcoal is converted to carbon monoxide, leftover is the non-combustible ash. Because temperatures are low due to heat loss and the mixing between gas and air is incomplete, combustion is also incomplete. In heating systems that use wood pellets or wood chips, therefore so-called primary air is supplied during the first step, followed by the second step whereby pyrolysis gas is then mixed with secondary air and is burned in a hot combustion chamber. In order to achieve high temperatures, the released energy is first flowed through a heat exchanger to heat water, which is then used for heating purposes or hot water. The ash is thereby partly carried out from the combustion chamber and partly blown away as dust with the exhaust gas, which is separated in larger plants in downstream separators. Ash consists essentially of calcium, potassium and sodium. It is a solid that remains when the carbon and hydrogen in wood are burned off by combustion.

The Lucerne researchers are studying the combustion processes on a 150 kW system. In addition, they create computer models of two sub-processes of a movable feed grate:

Modeling of the fuel conversion: The fuel bed model illustrates how the wood chips are converted into gases, ash, and unburnt carbon. With the model, the researchers are investigating how to achieve complete fuel conversion on the fuel-grate and at the same time, high burn-off of the gases with little spillover of air. The model enables the development of control and regulating concepts to acheive ideal fuel conversion on the grate under changing fuel properties.

Modeling of the pyrolysis gas flow: Using the method of computational fluid dynamics (CFD) the question of at what point and at what speed the (secondary) air must be injected into the combustion chamber is explored, so as to achieve the best possible mixture with the pyrolysis gas. A good mix is significant for the subsequent oxidation process: excess air, exhaust gases and fine particulate matter can in this way be kept low, not only at nominal but also at partial loads. In this context it is also worth mentioning that the Lucerne researchers have built up vast expertise in precisely measuring pyrolysis gases. BV

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