Problems in biofuel utilisation
A Swedish perspective

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Why?

Most people are – by now – aware of the risk of global warming and of the fact that one major issue to avoid this is an increased use of biofuels for energy purposes. However, the combustion of biofuels is even more complex than the combustion of coal.

Logistics

The bottlenecks in biomass utilisation are highly latitude-dependent. This is due to the fact that the specific productivity of biomass is less in the countries where the need of heating is the highest and vice-versa. The growth rate of forests in Sweden is equivalent to a logging residue production about 0.015 W/m^2 as an annual average and may be assumed to the order of magnitude of 0.075-0.1 W/m^2 in the forrestal areas of continental Europe.

Europe
Source: National Gegraphic

With average heat consumption in the order of 5-10 W/m^2 dwelling area (20 W/m^2 in Sweden), every m^2 of heated housing needs a fuel supply collected from 100-150 m^2 of forest land in the European continent while the same number becomes 10-fold in Sweden. In case of energy crops, the area needed may be reduced down to about 10 m^2 in continental Europe and to about 50-100 m^2 in Scandinavia.

The optimum size of the plant, with respect to the transport work needed for the fuel logistics, is thus dependant on the type of fuel available – whether it is forest residue fuels or if agrofuels can be used – and also on the location of the plant. Finally, any competition with cash-crops of one kind or the other must be taken into account from the individual farmers point of view.

Combustion properties

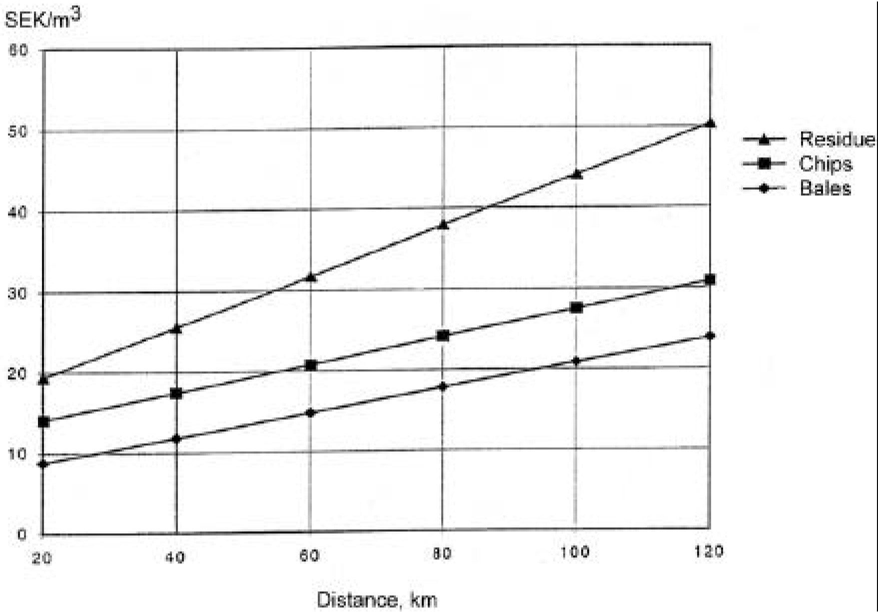
Just as ”coal” is merely a word to a combustion engineer - so is ”biomass” to an even higher degree. Biofuels used exhibit a wide range of ash-softening temperatures (700 - 1150+ ^oC). The water content of the fuel as fed to the boiler may vary within the range 25 - 55 %

(wood chips and logging residues) down to below 10 % (saw-mill residues) and particle shapes and -sizes may be anything. It is not uncommon that wet chips and dry cutter shavings should be burnt in the same boiler resulting - from time to time - in high emissions of PAH. With nitrogen contents varying from 0.1 - 1.0 % it becomes obvious that the NO_x-control system suffers severe problems and that the emissions vary significantly over time. Heavy metals such as cadmium may be present to a high concentration in some fuels - especially in juvenile hardwood fertilised with sewage sludge - while chlorine may be a problem with some agrofuels. Finally, the fibrous structure of the biofuels makes them very hard to grind into reasonably isometric particles. Thus the feeding of pulverised biofuels poses problems unheard of in coal-powder feeding.

In spite of this problem catalogue, biofuels must be used as one measure to counteract the threat of global warming.

Present developments in Sweden

As mentioned in the introduction Sweden is characterised by low biomass growth rates (equivalent to 0.015 W/m^2 counted as logging residues) and relatively high demands for heating (approx. 20 W/m^2 counted as an annual average for dwelling areas). Thus the areas needed to supply a municipality become large and the energy for transport becomes significant.



Fuel transportation costs

A common rule of thumb indicates that mean transport distances exceeding 100 km are uneconomic and plants of sizes 5 MW_{th} and less, down to just below 1 MW_{th}, are currently being commissioned in Sweden at an increasing rate. Plants in this size are, so far, for heat production only. For domestic stoves and boilers the pellet market is rapidly expanding.

For economic reasons the plants in the interval 1-5 MW_{th} are mainly of the moving-grate type, which is fairly robust with respect to ash softening but does not lend itself very well to any advanced process control. In areas where saw-mills are abundant, or where short-rotation energy forestry is viable, larger plants are being built. These are - in many cases - cogeneration plants in the range of 100 MW_{th}. CFB-technology is dominant for these plants. Biofuel gasification with combined-cycle is lurking around the corner of time but has not yet had its break-through.

What is now seen in Sweden is thus a rapid expansion of very small district heating networks making use of simplified tubing and extremely compact and cheap heat exchangers. The current price for district heat paid by the Swedish end customer is about 0.050 - 0.065 Eur/kWh, so capital costs must be kept at a minimum in these small systems. At the same time the fuel cost has to be low and unspecified wood chips from logging residues may be obtained at prices below 0.01 Euro/kWh. Any upgraded fuels - dried, compacted or both - cost about double.

Fuel collection development

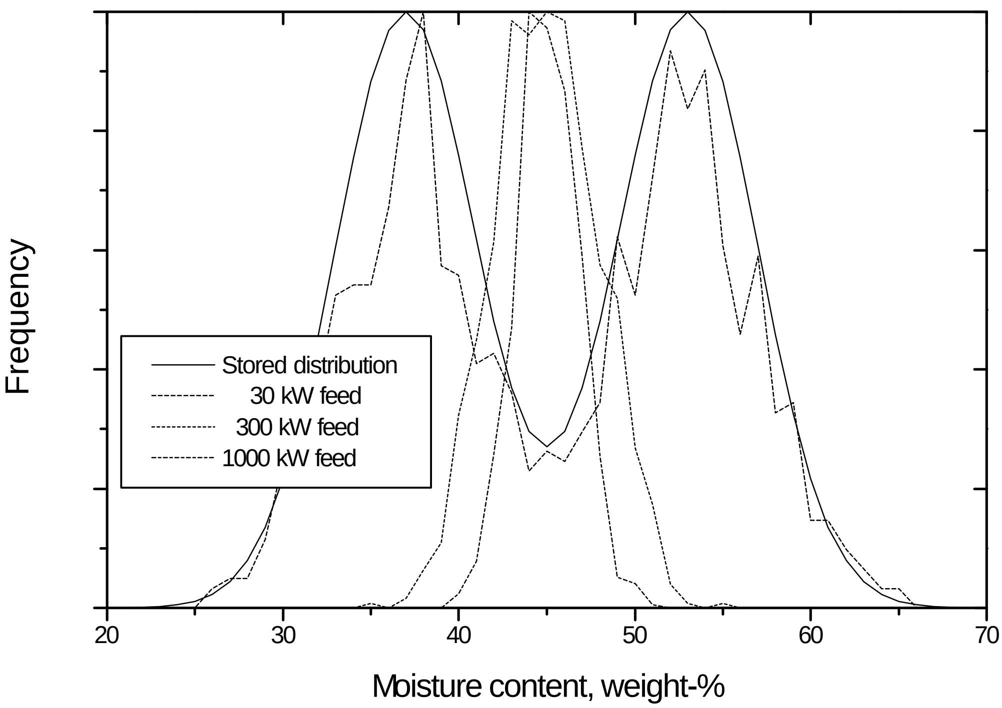
The fuel collection techniques do thus develop rapidly and new balers as well as machines for bundling of residues (branches and treetops) are marketed. This trend tends to conserve the prices for unclassified fuels while the costs for upgraded fuels are slowly rising or will soon be.

Loading forest residue bundles

The evolution of hydrocarbons, as well as the development of fungal spores and allergenes during storage is also being investigated in research projects, since this may be affected of the fuel handling techniques.

Combustion problem areas

The main combustion problems seen are the spread in ash properties and the spread in fuel quality. This becomes more pronounced in small-scale, chips-fired plants. The statistical consequence of this is that even when if the fuel is taken from the very same pile, the smaller plant will experience a more variable fuel quality than the larger plant. This is exemplified in the figure below where a bimodal moisture distribution is fed into three different plants at 30 kW, 300 kW and 1 MW. It is clearly seen how the smallest plant will experience two different fuels, on a second-to-second basis, one with 37 % moisture ± 12 and another with 53 % ± 12. The 300 kW unit will, in contrast, experience a fuel with 45 % moisture ± 9 % and the 1 MW unit "sees" a fuel with moisture content 45±5 %.



Fuel moisture distributions

The bimodal fuel moisture distribution is realistic for a chip-pile stored outdoors for a period of six months. During this period, the fuel in the central parts of the pile dries, due to the heating from micro-biological activity, while the water thus evaporated condenses in the outer, cooler, region of the same pile.

The variations shown above, in moisture content, are not independent of other quality measures but are among the most important factors as biofuels are concerned. The content of lignin, cellulose and hemicellulose as well as the ash content and several other components are also variable. A secondary effect of the moisture content is that the adiabatic flame temperature varies and that the local oxygen concentration varies since the water vapor dilutes the combustion air. Thus the conditions for hydrocarbon burnout are highly variable, especially in smaller fireplaces.

To counteract the above phenomena there is only one main guideline: The smaller the plant - the higher demands must be put on the fuel. From an environmental or combustion technology viewpoint it is clear that small scale biofuel utilisation demands upgraded fuels such as pellets, briquettes or the like. However, this is counteracted by economy.

Conclusions

The conclusion of the above is that what is currently happening is a rapid number expansion of more or less uncontrollable grate-fired units in small scale fired with the most unclassified fuel ever seen.

The NO_x-emissions are relatively high from these plants, in excess of 120 mg NO_2/MJ fuel input. For comparison: The best boilers in the 100 MW-range are below 20 mg/MJ, but then that is with SCR which is not viable in the small range.

This development calls for a research effort: How do we maintain low-NO_x and low-PAH when firing an unclassified fuel in small boilers with no sophisticated process control? There is a need to develop rapid dynamic process control models to cope with this. There is also room for innovative thinking about the combustion technology itself.