COMBUSTION OF WOOD BRIQUETTES IN STOVES

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ABSTRACT: Increased wood fuel demand for households and new European biomass fuel standards have stimulated a growing use of wood briquettes in Europe. But concerning their pollutant emissions when applied in residential stoves there is contradictory information about possible improvements compared to regular wood logs. Influencing factors are given by the raw material used, briquette shape and fuel composition. For combustion trials several such fuels were selected: four wood briquettes of different shapes (cylindrical, cylindrical with hole, cubiform and eight edged with hole), two briquettes made of pure bark, one briquette of brown coal and as reference fuel wood logs from beech and spruce. All fuels were consistently applied in three different stoves (two chimney stoves of 6 and 8 kW and one tiled stove insert of 8 kW) representing the state of the art in Germany. The results show that the combustion of wood briquettes usually causes higher particle emission compared to log wood, but briquettes perform quite comparable to wood logs when regarding carbon monoxide (CO-) and organic gaseous carbon (OGC)-emissions. Round briquettes with and without central hole were found favourable types. Pure bark briquettes were found less suitable due to increasing CO and OGC emission and due to higher particle emissions when sampled from diluted flue gas at temperatures below 50°C. For bark and coal briquettes the thermal efficiency is about 10 % lower compared to log wood or pure wood briquettes.
Keywords: chimney stove, tiled stove insert, wood briquettes, bark briquettes, particle emission

1 INTRODUCTION AND OBJECTIVES

Wood briquettes are mainly applied in wood stoves for residential heating. Such use is usually deemed to be relatively environmentally friendly as the briquette properties are assumed to be easily kept constant by means of quality assurance and standardisation (e. g. DIN EN 14961-3 [1]). However, a recent study had raised discussions about this assumption being generally applicable [7]. It had shown that the use of wood briquettes in stoves can lead to excessive dust formation, e. g. in a tiled stove insert they were about 3 times higher than for regular wood logs. A similar observation was made for briquettes which were made of pure bark; here the total dust emission was 2- to 3-times higher than for conventional wood logs [7]. These findings had raised questions about the shape, quality and composition of briquettes being decisive for pollutant emissions. This was particularly discussed in view of another study which revealed a large quality variation for wood briquettes as found in an extensive market screening where 36 briquette samples had been collected from the German market for analysis and evaluation [5].

It was therefore the aim of this research to evaluate wood briquette performance in such residential wood stoves which were deemed being typical applications and representing the state of the art in Central Europe. The focus was set on different wood briquette types (shapes) and the research aimed at a differentiation between pure wood briquettes (including the natural adhesive bark) and pure bark briquettes, although bark briquettes are today not permitted for use in stoves in Germany (provided that the emission directive 1. BImSchV [6] is interpreted carefully). Nevertheless, such bark briquettes are sometimes used for longer heat provision and to conserve the ability to re-ignite the fire easily. This purpose is sometimes also fulfilled by using brown coal briquettes which can legally be applied in stoves in Germany, given that they are declared suitable by the respective stove manufacturer. Therefore such coal briquettes were also included into the scope of this study.

2 MATERIAL AND METHODS

2.1 Wood stove appliances used

For the trials two different chimney stoves (i. e. light stove with usually large window) as well as a tiled stove insert were chosen, Figure 1.

Figure 1: Applied wood stoves (left: chimney stove 1, middle: chimney stove 2, right: tiled stove insert)

Chimney stove 1 was a Buderus blueline No. 12 with a nominal heat power output of 8 kW and a combustion chamber of 37 litres. Chimney stove 2 was a Fireplace Santa Fe with a lower nominal heat power output of 6 kW and a combustion chamber of 25 litres; it represents the low-cost segment. The third furnace was a tiled stove insert Brunner KKE 33 with a nominal heat power output of 8 kW and a combustion chamber of 35 litres. Both chimney stoves were equipped with a grate, while the tiled stove insert had no grate. Only the chimney stove 2 was declared suitable for coal combustion and it was also equipped with additional secondary air inlets from the backside of the combustion chamber.

2.2 Combustion test stand

All measurements were performed at the combustion test stand of the TFZ in Straubing. Figure 2 shows the applied test rig with flue gas and dilution tunnel on which all measurements were performed.

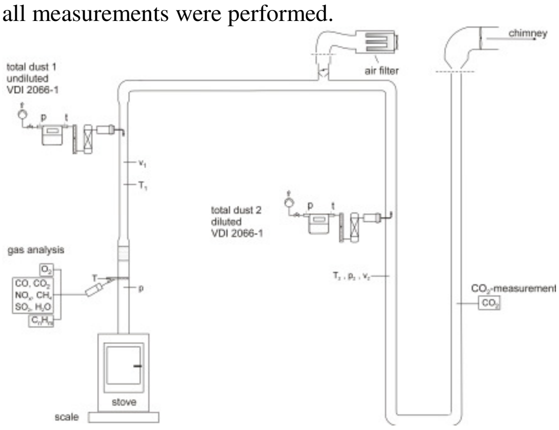

Figure 2: Test stand with flue gas tract and dilution tunnel for flue gas emission measurements

The stoves were placed on a scale in order to record the mass loss during combustion. Flue gas temperature was measured with a suction pyrometer in accordance to DIN EN 13240, it was combined with the gas sampling [1]. The flue gas tunnel for dust sampling was reduced to an effective inner diameter of 64.4 mm in order to increase the velocity for a reliable isokinetic dust sampling. Gas temperature and velocity near the undiluted total dust sampling were continuously recorded for volume flow calculations. Downstream of the dust sampling the inner diameter was widened to 150 mm again before the flue gas was diluted with filtered air. In the dilution tunnel having a diameter of 150 mm the second total dust sampling was performed in parallel, following the VDI-Guideline 2066 [3]. The temperature in the dilution tunnel was consistently kept below 50 °C throughout all tests. CO_2 was determined in the diluted flue gas for the calculation of the dilution ratio.

2.3 Procedure of performing combustion trials

The stoves were heated up over one or two initial batches using spruce wood without bark, except for the trial with beech wood. Then always three combustion batches were performed. For each batch the measuring started right after loading when the door was closed. The measurement of a batch was terminated when only 4 wt.-% of the original mass of the loaded fuel was reached. For the two pure bark briquettes as well as the brown coal briquette the measurement had to be finished at an earlier moment due to a higher ash content. Moreover, small intermediate batches with spruce wood had to be applied in order to achieve comparable starting conditions for each bark briquette batch, too.

The determination of total dust was made discontinuously by sampling according to the VDI-Guideline 2066 [3] (method with filtering head device and method with plane filter). In this method the dust load of a partial flue gas stream is retained in a dust collection system. For retention a stuffed quartz wool cartridge with a subsequent quartz fibre plane filter (retention 99.998 % according to DOP (0.3 µm), diameter 45 mm) was used. Both media were combined in an out-stack filter head device (see Figure 2). The sampling tract outside of the flue gas tract was heated in order to avoid any additional condensation. Behind the filter the sampled gas was conveyed into a gas drying unit and the volume flow was determined. Dust was determined gravimetrically after thermal filter treatment at 120°C and conditioning in a desiccator. The unloaded and loaded filters were then weighed on a precision balance (Mettler Toledo XP 56, maximum load 56 g, resolution: 1 µg). Apart from the dust collected on the plane filter and the stuffed quartz wool cartridge, the particle deposition in the sampling tract was also accounted for. This was done by washing the sampling tract with desalinated water (two to three times) and with acetone and desalinated water again.

For all three batches the undiluted flue gas was always analysed for gaseous compounds and for total dust. In the diluted flue gas dust was only determined for the first and third batch.

3 FUELS USED

3.1 Wood logs

For a better evaluation of the combustion behaviour of wood and bark briquettes also beech and spruce wood without bark were used in the same furnaces. Beech and spruce wood were applied in the shape of the test fuels in accordance to the Norwegian test standard for wood heater S (NS 3058-1 [4]), see Figure 3. The test fuel logs had a cross section of 7 x 7 cm. For constant mass the length of the beech wood was adjusted to the mass of the spruce wood.

Figure 3: Beech and spruce wood logs without bark in test fuel shape

3.2 Briquettes

Four wood briquettes, two pure bark briquettes and a brown coal briquette were selected from the market. The selection was made based on the results of a previously performed survey where a total of 36 briquettes types had been chosen and analysed for numerous fuel properties and compounds [5]. The different shapes of the selected wood briquettes are shown in Figure 4. The shapes of the bark and brown coal briquettes are displayed in Figure 5.

Figure 4: Wood briquettes of different shape

Figure 5: Two pure bark briquettes of different shape and a brown coal briquette (picture right)

All fuels were combusted in each tested furnace except for brown coal briquette which was not used in the tiled stove insert. The mass per batch was kept constant depending on the furnace nominal fuel load requirement.

3.3 Chemical and combustion properties of the fuels

Beech and spruce wood without bark differ slightly in their chemical composition and combustion properties. Both fuels contain only a small amount of ash. The main components of all tested fuels as well as the net calorific values are summarized in Table I.

As expected, brown coal consists of a higher fraction of carbon leading to an increased net calorific value. The ash content for all wooden biomass ranged between 0.37 and 1.5 wt.-% (Table I). Both pure bark briquettes had an elevated ash content of 9.23 and 8.4 wt.-%, respectively.

Table I: Main components and net calorific value of the fuels used for combustion trials

Fuel	C	H	O	N	Ash	Net calorific value
	wt.-% (dry basis)					kJ/kg
spruce logs without bark	51.8	6.4	41.3	0.17	0.37	18,923
beech logs without bark	50.0	6.4	42.9	0.13	0.65	17,963
briquette round with hole	50.8	6.0	42.9	0.00	0.31	19,026
briquette round without hole	51.6	6.2	40.6	0.07	1.53	19,632
briquette cubiform	52.0	6.4	41.3	0.05	0.25	19,646
briquette eightedge	50.9	6.1	42.6	< 0.05	0.45	18,884
bark briquette cubiform	49.9	5.3	35.3	0.29	9.23	18,249
bark briquette sixedge	49.2	5.2	36.7	0.44	8.43	18,165
brown coal briquette	65.3	4.7	24.7	0.74	4.23	24,921

Further components such as Ca, Mg, Si as well as heavy metals such as Cd, Cr and Cu are summarized in Table II. The high Si content in the sixedge bark briquette indicates an impurity of the fuel, probably caused by soil pollution. This partly explains the high ash content of this fuel type.

Table II: Chemical components and heavy metals in the fuels used for combustion trials

Fuel	Ca	Mg	Si	Cd	Cr	Cu
	mg/kg (dry basis)					
spruce logs without bark	940	81	1,160	0.3	1.9	0.7
beech logs without bark	955	408	1,580	0.2	3.6	2.7
briquette round with hole	780	150	< 50	< 0.2	< 1	2
briquette round without hole	4,020	360	1,730	< 0.2	< 1	3
briquette cubiform	990	150	< 200	0.2	< 1	< 1
briquette eightedge	1,110	150	800	3.0	< 1	< 1
bark briquette cubiform	13,500	1,670	2,120	0.4	2	3
bark briquette sixedge	16,000	1,100	14,000	0.5	48	7
brown coal briquette	10,000	3,900	120	< 0.2	4	< 1

The aerosol forming elements S, Cl, K, Na, Zn and Pb of all fuels are given in Table III. The brown coal briquette contains the highest amount of such aerosol elements with 5,513 mg/kg in total (dry basis), followed by the two bark briquettes with 3,200 and 3,661 mg/kg.

Table III: Concentration of aerosol forming elements in the fuels used for combustion trials

Fuel	S	Cl	K	Na	Zn	Pb
	mg/kg (dry basis)					
spruce logs without bark	60	100	841	17	7.2	7.2
beech logs without bark	60	40	1,530	18	3.9	1.8
briquette round with hole	100	< 50	400	39	14.0	< 1
briquette round without hole	1,800	124	710	230	2.0	< 1
briquette cubiform	< 300	55	270	7	9.0	< 1
briquette eightedge	< 300	153	510	13	4.0	3.0
bark briquette cubiform	400	113	2,750	330	67.0	1.0
bark briquette sixedge	400	120	2,300	280	97.0	3.0
brown coal briquette	3,000	270	240	2,000	3.0	< 1

4 RESULTS OF COMBUSTION TRIALS

4.1 Combustion of wood briquettes

In pre-tests the observation had been made that wood briquettes generally tend to increase their volume during combustion, Figure 6. Thus there was a danger of being stuck between the walls in the firebox and which can lead to smouldering combustion by losing contact to the fire bed. It was therefore concluded, that the longer wood briquettes (both round briquettes) had to be broken before their use. The cubiform and eightedge wood briquette did not have to be broken before use.

Figure 6: Wood briquettes right after recharging the stove (left) during initial combustion (middle) and finally being stuck in the firebox (right)

The combustion of round briquettes with and without centrical hole caused the lowest CO emission for all stoves, Figure 7. They were even below the CO values emitted by beech wood combustion. Slightly higher CO emissions were detected for the cubiform shaped wood briquettes and the eightedge with centrical hole in all stoves.

Unexpectedly the CO emissions from chimney stove 1 are higher than from the low-cost chimney stove 2. The improved performance can probably be attributed to the additional secondary air inlet at the backside of the firebox in chimney stove 2.

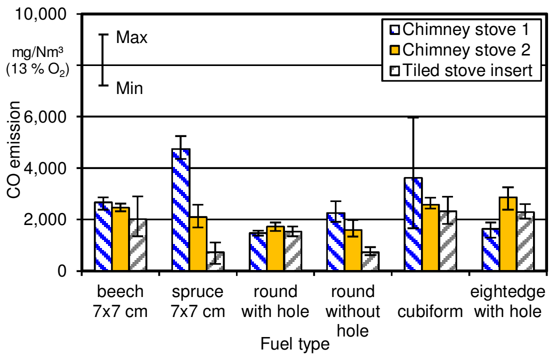

Figure 7: Combustion behaviour of wood logs (7x7 cm) and wood briquettes regarding CO emission in two chimney stoves and one tiled stove insert

Typical for batch combustion is the increased emission of organic hydrocarbons (OGC), especially just after recharging. The OGC emissions from wood briquette combustion compared to wood logs are summarized in Figure 8. As shown for the CO-emissions, the disadvantages of chimney stove 1 compared to chimney stove 2 again become visible, while the tiled stove usually performs best. It can also be seen that both round wood briquettes cause lowest OGC emissions in this comparison while the highest values were observed with cubiform wood briquettes, Figure 8.

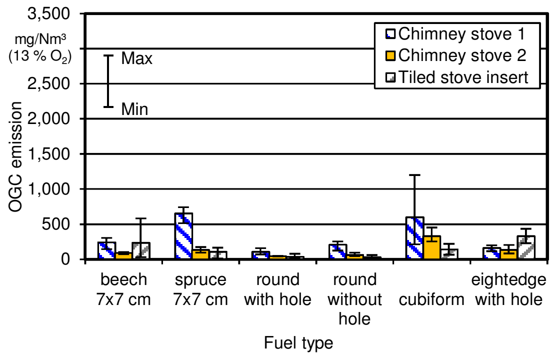

Figure 8: Combustion behaviour of wood logs (7x7 cm) and wood briquettes regarding OGC emission in two chimney stoves and one tiled stove insert

Comparing the values for particle emissions in the undiluted flue gas (Figure 9) it has to be stated that the highest emissions are observed for the low cost chimney stove 2. The usually claimed advantage of hard wood (here: beech) seems to depend also on the stove type or the stove geometry, as that the particle emissions were lower for chimney stove 1 and the tiled stove but mostly higher for chimney stove 2.

For all wood briquettes higher particle emissions in the undiluted flue gas were detected. The increase could be due to the fact that wood briquettes increase their volume and tend to break apart during combustion so that small ash particles are entrained from the briquettes into the flue gases. This is here more pronounced for chimney stove 2 with the smallest combustion chamber of only 25 litres. The other two stoves have a volume of 35 to 37 litres. In addition the heating box which was connected to the tiled stove insert (see Figure 1) may favour some particle deposition on the walls and thus prevent emission. The dust emission values for both round briquettes are again lower than for the other two types of wood briquettes, Figure 9.

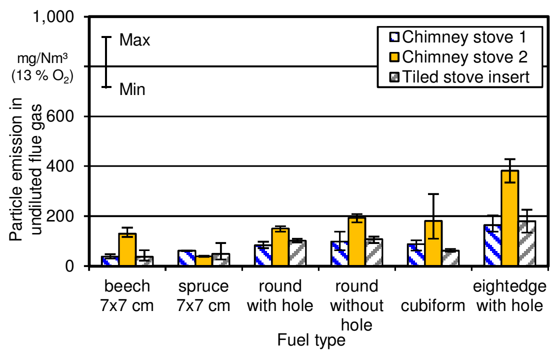

Figure 9: Combustion behaviour of wood logs (7x7 cm) and wood briquettes regarding particle emission in undiluted flue gas for two chimney stoves and one tiled stove insert

A slight increase in particle emission due to dilution of the flue gases and therefore partial condensation of organic hydrocarbons can be seen in Figure 10 for all fuel types and stoves. The increase ranges from 6 % to 225 % depending on fuel type and stove.

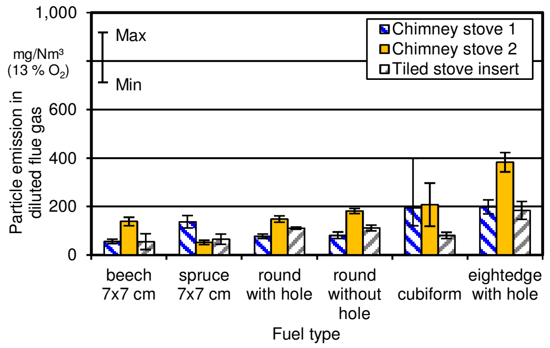

Figure 10: Combustion behaviour of wood logs (7x7 cm) and wood briquettes regarding particle emission in diluted flue gas for two chimney stoves and one tiled stove insert

Figure 11 summarizes the thermal efficiency achieved with the different fuels. A slight increase of thermal efficiency was noted for the combustion of wood briquettes (about 75 % in chimney stoves) compared to log wood (about 72 % in chimney stoves). Both chimney stoves achieved comparable thermal efficiencies. As expected, the thermal efficiency of the tiled stove insert was as high as 90 % in average. This can be attributed to the heating box with large surface for heat transfer. However, in practise the heating box is usually walled by a mineral heat storing material and thus the efficiency may be lowered as a result of a reduced heat exchange effect.

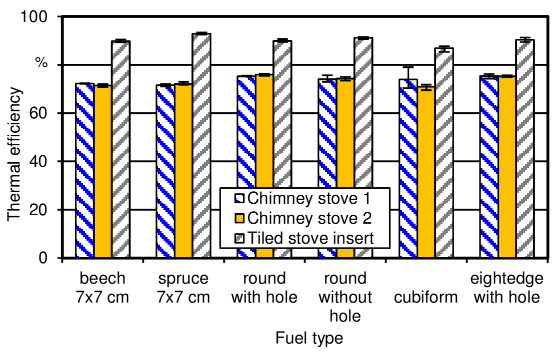

Figure 11: Thermal efficiency of using wood logs (7x7 cm) and wood briquettes combustion in two chimney stoves and one tiled stove insert

4.2 Combustion of bark and coal briquettes

Pure bark briquettes and brown coal are usually used to maintain a hot bed of ember to delay the time of recharging. However, this operation can cause more or less smouldering conditions in the stoves which leads to extremely high emission, Figure 12 to Figure 15. The brown coal briquette was not tested in the tiled stove insert (not suitable according to manufacturer). All results are compared to the trials with reference log wood fuels (7x7 cm) and presented in the same way as in chapter 4.1.

The highest CO emission in all combustion trials was achieved for both pure bark briquettes and brown coal for all three stoves used in this comparison, Figure 12. The lowest impact on CO emission was observed for chimney stove 2 which was equipped with additional secondary air inlets (see Figure 1). Moreover, chimney stove 2 was declared suitable for coal briquettes by the manufacturer.

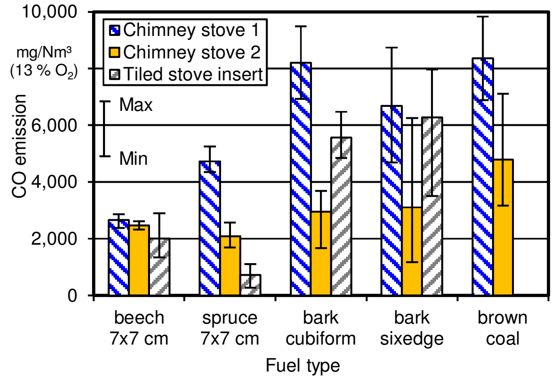

Figure 12: Combustion behaviour of wood logs (7x7 cm) and pure bark briquettes regarding CO emission in the flue gas for two chimney stoves and one tiled stove insert

Due to the smouldering (only small flames visible during measurement, if any) also a very high concentration of OGC was measured for bark briquettes. The highest OGC concentrations were always emitted by chimney stove 1, while only one fourth of OGC was emitted from chimney stove 2, Figure 13 . Especially for the combustion of bark briquettes high deviations of the obtained values occurred.

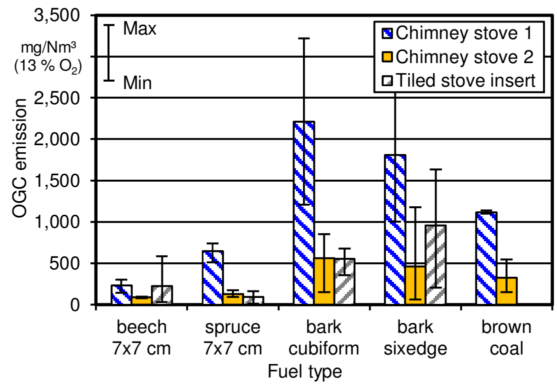

Figure 13: Combustion behaviour of wood logs (7x7 cm) and pure bark briquettes regarding OGC emission in the flue gas for two chimney stoves and one tiled stove insert

In the undiluted flue gas no clear differences in particle emission were observed between bark briquettes and log wood, Figure 14. In many cases the values are even lower for bark fuel. It may be attributed to the relatively slow combustion of bark briquettes which prevents small ash or unburnt particles from leaving the combustion chamber. In addition, bark briquettes do not increase their volume during combustion or fall apart in the chamber.

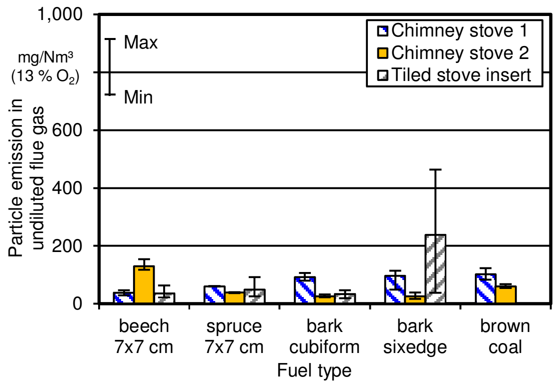

Figure 14: Combustion behaviour of wood logs (7x7 cm) and pure bark briquettes regarding particle emission in undiluted flue gas for two chimney stoves and one tiled stove insert

If, however, the particles are sampled from diluted flue gas, large differences become visible, Figure 15. This particularly applies if high fractions of OGC are emitted, as for chimney stove 1, Figure 13. Due to condensation of organic compounds in the flue gas the measured particle emission increases considerably. This increase is less pronounced for chimney stove 2 because the fraction of OGC in the undiluted flue gas is much lower as mentioned earlier (Figure 13).

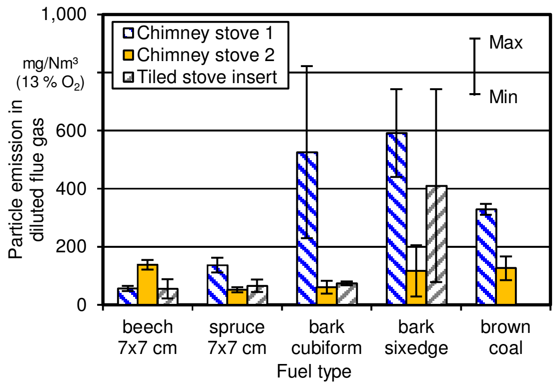

Figure 15: Combustion behaviour of wood logs (7x7 cm) and pure bark briquettes regarding particle emission in diluted flue gas for two chimney stoves and one tiled stove insert

Compared to log wood combustion a 10 % decrease in thermal efficiency was determined for both bark briquettes and for the combustion of brown coal in all stoves, Figure 16. As for pure wood briquettes (chapter 4.1) the tiled stove performed better than the chimney stoves due to the extra heat yields via the attached heating box.

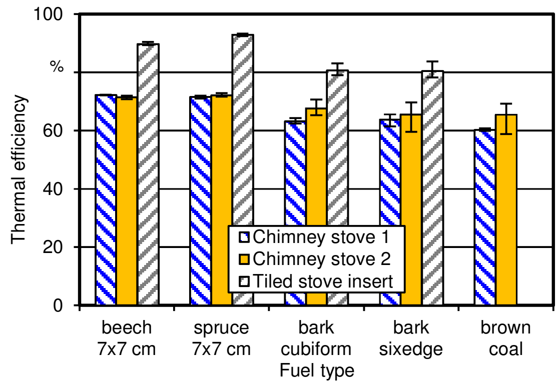

Figure 16: Thermal efficiency of using wood logs (7x7 cm) and pure bark briquettes combustion in two chimney stoves and one tiled stove insert

It can be summarized that briquettes from pure bark are less suitable for stoves especially due to the elevated CO and OGC emission. This was also found in a previous study with a different chimney stove using the same sixedge bark briquette [7].

5 CONCLUSIONS

This investigation has shown that low-cost chimney stoves do not necessarily cause higher emissions compared to other chimney stoves. The tiled stove insert has almost consistently shown a better emission behaviour while providing highest thermal efficiencies of around 90 %.

The following recommendations regarding the combustion of briquettes can be given:

- Wood briquettes in general show a similar emission behaviour for CO and OGC as log wood.
- The combustion of wood briquettes causes higher particle emission compared to log wood.
- In general round briquettes with and without hole achieve lower emissions than other briquette shapes.
- Pure bark briquettes are less suitable for chimney stoves and tiled stove inserts due to the high increase in CO and OGC emission and due to higher particle emissions in the cooled flue gas.
- Thermal efficiency is about 10 % lower if bark briquettes are used compared to log wood or pure wood briquettes (from wood with natural share of adhesive bark).
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It can finally be stated, that differences in fuel composition and burning quality concerning total particle emissions become highly visible when the particle sampling is performed after a flue gas dilution. The dilution and cooling step is obviously responsible for condensation of organic gaseous compounds which add up to the measured total dust. Thus, the sensitivity towards improper fuel qualities is enhanced. These interactions are also in good conformity with correlations found in previous studies concerning dilution practises (see [8]).

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