# Experimental Study on Hemp Residues Combustion in a small Scale Stationary Fluidized Bed Combustor

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## ABSTRACT

Stationary fluidized bed combustion (SFBC-400, diameter 400 mm) has been proved to be an effective way of converting biomass wastages (Hemp residues) into clean energy. It has been received wide research attention in terms of its potential as an economic and environmentally acceptable technology for burning biomass and organic wastages. This paper introduces an experimental study of Hemp residues combustion in a SFBC. Experiments on ranges from 80 to 200 kW combustion test facility capacity show that Hemp residue Combustion temperature must be on ranges from 800 to 825° C. Temperature, volume and the concentrations of exhausted emissions (e.g. $CO_2$, $O_2$, CO, NO, $NO_X$, $SO_2$) are measured by dedicated sensors at different profiles inside the combustor, along its height and in the flue gas duct where the emission is exhausted.

**Keywords:** Hemp residues, agricultural residues, combustion, SFBC, emission, energy, Viet Nam

## 1. INTRODUCTION

In recent years, several developed countries in the world focussed their attention to renewable energetic technologies, especially to biomass technologies. The knowledge in this field had developed fast and strongly. Nowadays, many further countries are developing and applying renewable energy sources, for example America, Japan, China, especially Germany.

The main reason is the traditional fuels (coal, natural gas, petroleum, etc.) are becoming exhausted. Besides, traditional fuels cause air pollution (Stout and Best, 2001).

In difference to other renewable energy technologies, biomass energy is not only replacing traditional energy supply but also contributing considerably to the goal of reducing change of climate, using e.g. wastages, residues of agriculture, silviculture to energy (heat, power). In addition, biomass has another advantage to compare with other renewable energy technologies (wind energy, solar energy, wave energy etc.) in two respects: first, not like them, biomass energy can be renewable and is available when needed. Second, based on biomass heat and power can be generated simultaneously and continuously. Biomass can be stored for longer periods. The costs of the supplied bio fuels vary, it depends on local prices, transportation costs, etc.

In global size now, biomass is the 4$^{th}$ great energetic source that is taking about 14% to 15% of the general used energy in the world (Nguyen, 2006). In developing countries, biomass is a great energetic source (Nguyen, 2006; Stout and Best, 2001). Averagely it contributes approximately 35% of the general supplied power (Nguyen, 2006). In Vietnam, according to some energy experts in the German co-operating organization ("Gesellschaft für Technische Zusammenarbeit-GTZ"), Vietnam has a great potential of bio energy but does absolutely not know to use it.

Similar results were obtained by (Nguyen, 2006; Nguyen and Tran, 2004). Vietnam now has more than 25 million tons wood biomass energy, more than 53 million tons biomass from agricultural residues (Table 1). Following (Nguyen, 2006; Renewable Energy In Asia: the Vietnam report, 2005; IET, 2004; and England and Kammen, 1993), the potential of biomass of Vietnam is significant. Residual biomass includes: rice husk, sugarcane bagasse, cane trash, cassava, coconut shells (Fig. 1), maize, wood, bio-rubbish of the cities, agricultural residues etc.. However, studies have shown that these residues could be combusted/gasified to produce heat, electricity or combined heat and power (CHP) or processed into liquid fuels (Jekayinfa and Omisakin, 2005; Soltes, 1983; Barnard and Kristoferson, 1983; Enweremadu et al., 2004). Especially in Vietnam, these biomasses are resources that can be used for generation of electricity. The bagasse potential generated from existing mills is estimated to support 100 $MW_{th}$ per year ($MW_{th}$- thermal power in MW) of cogeneration capacity. Especially, the technical potential of rice husk is estimated at 450 $MW_{th}$ per year. But the two-thirds of biomass are used for animal feed or cooking. The available potential is estimated to be around one-third to one-half of the theoretic potential and placed at around 150-200 $MW_{th}$ per year (IET, 2004). Beside sugar cane, other biomass sources are absolutely not exploited to generate power (Nguyen, 2006, and Pham, 2005).

Table1. Potential of biomass energy from wood and agricultural residues in Vietnam (Nguyen, 2006; Pham, 2005, and Nguyen and Tran, 2004)

| Supplying and Source of material | Potential (Millions Ton) | Relationship (%) |
|---|---|---|
| Natural forest | 6.842 | 27.36 |
| Artificial forest | 3.718 | 14.87 |
| Natural soil no forest | 3.850 | 15.39 |
| Distributed tree | 6.550 | 26.19 |
| Industry and fruit-tree | 2.400 | 9.59 |
| Waste wood | 1.649 | 6.59 |
| **Total** | **25.01** | **100.0** |
| Straw, wheat | 33.52 | 62.69 |
| Rice husk | 6.50 | 12.17 |
| Bagasse | 4.45 | 8.32 |
| Other Wastes | 9.00 | 16.83 |
| **Total** | **53.47** | **100.0** |

According to the World Bank in 2001, Vietnam used only 11% potential of the currently available bio energy (IET, 2004). Biomass utilisation is connected with a lot of advantages and acceptable costs. Data in table 2 present economic values of use energy from agricultural residues and traditional materials.

Table2. Economic effect of use of agricultural residues and traditional fuels for burning

| Source of agricultural residues | | | Other Source of fuels | | |
|---|---|---|---|---|---|
| Fuels[1)] | NCV[*)] (MJ/kg)[1)] | $USD/kg Fuel[2)] | Fuels[1)] | NCV[*)] (MJ/kg)[1)] | $USD/kg Fuel[2)] |
| Rice husk | 14.4 | 0.002 - 0.003 | Anthracite | 31.4 | 0.08 |
| Rice straw | 14.6 - 15.0 | 0.004- 0.005 | Brown coal | 11.3 | 0.05 |
| Maize haulm | 14.7 | Free of cost | Peat | 28.5 | 0.07 |
| Maize-cob | 15.4 | Free of cost | Diesel | 35.0 | 0.218 |
| Coffee husk | 16.6 | Free of cost | Natural gas | 40.0 | 3.64 |
| Bagasse | 8.2-16.2 | Free of cost | | | |
| Wood and other wood | 10.9-16.6 | 0.012-0.017 | | | |
| Residues from kapok | 11.9 | Free of cost | | | |
| Coconut shells | 17.9 | Free of cost | | | |
| Sawdust | 18.5-19.0 | Free of cost | | | |
| Residues of cashew nut | 24.0-25.0 | Free of cost | | | |

*) - according to ISO: net calorific value (NCV); 1) - source: Pham and Thang, 2003

2) - status: the year 2006, and source: Vietnam Statistical Yearbook, 2006

It has indicated that “NCV” of traditional materials, approximately 1kg of Anthracite, is 1.5 - 2.5 times higher than biomass. Here the price of one kg of Anthracite is approximately 30 - 35 times higher than this one kg of rice husk. Clearly, using burning materials from agricultural residues will get more benefit than others. Vietnam can salvage this profuse biomass energy source to generate heat, power or CHP.

Utilization of biomass energy is an effective form for Vietnam to get new opportunities for agriculture and forestry. Another goal is reducing green house effect, diversifying energy sources, and realizing a growing supply with electric energy of the whole country. Additionally, by this can the rising petrol costs be compensated.

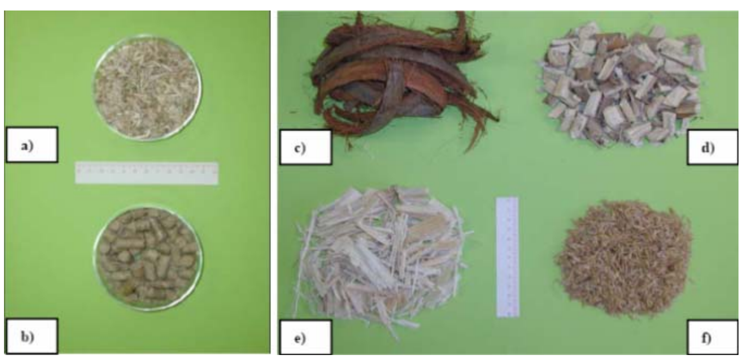


Fig.1. Experimental materials (a, b- Hemp- residues and pellets), and biomass of Vietnam (c- Coconut shells, d- Cassava residues, e- Bagasse, f- Rice husk)

From the condition and the role as analysed above, the actual “Experimental study of burning Hemp residues in SFBC-400” at the Chair of Environmental Engineering (CEE), University of Rostock, Germany has an important meaning. In this study the properties of Vietnamese biomass on the efficiency of the SFBC-400 combustor and exhaust emissions are implemented. But because of objective terms with the SFBC-400 plant only similar biomass generated in Germany can be investigated. The biomass investigated is Hemp residues (Fig. 1). It has nearly the same properties such density, according to ISO net calorific value (NCV) of fuel etc. particularly the physical, chemical properties like components of carbon (C), oxygen (O), hydro (H), nitrogen (N), sulphur (S), ash (a), water (w) as rice husk, bagasse, coconut shells, cassava residues in Vietnam. But ash compositions can be different. In Table 3 these properties are presented and their characteristics with biomass in Vietnam can be compared.

This paper presents the experimental investigations of Hemp residues combustion in SFBC-400. The objective is to obtain combustion characteristics and composition of exhaust gases by using selected biomass as a fuel.

## 2. MATERIALS AND STUDY METHOD

### 2.1 The Properties of Experimental Materials

The experimental fuel here is Hemp residues. This fuel has similar properties as some biomass in Vietnam. The chemical properties and NCV of this fuel will be analysed to clear the chemical components. The analyse results of the material above is compared with the biomass of Vietnam in Table 3 and Fig. 2. The comparison shows that the fuel properties of biomasses are basically the same. Rice husks attract attentions because of its high ash content. All values are produced in own analyses.

Table 3. Comparison of NCV, chemical compositions of biomasses (w, fuel-moisture; a, fuel-ash)

| Component Fuels | (C) (kg/kg) | (H) (kg/kg) | (O) (kg/kg) | (N) (kg/kg) | (S) (kg/kg) | (a) (kg/kg) | (w) (kg/kg) | (NCV) (kJ/kg) |
|---|---|---|---|---|---|---|---|---|
| Hemp residues [1), *)] | 0.4480 | 0.0598 | 0.3572 | 0.0051 | - | 0.0236 | 0.1063 | 16,254 |
| Rice husk[2)] | 0.3979 | 0.0523 | 0.3863 | 0.0013 | - | 0.1392 | 0.0230 | 15,196 |
| Coconut shells[2)] | 0.4622 | 0.0520 | 0.4163 | 0.0026 | - | 0.0300 | 0.0369 | 17,408 |
| Cassava residues[2)] | 0.4434 | 0.0576 | 0.4237 | 0.0065 | - | 0.0450 | 0.0238 | 15,942 |
| Bagasse[2)] | 0.4638 | 0.0576 | 0.4519 | - | - | 0.0074 | 0.0193 | 16,686 |

1) - Fuels of Germany; 2) - Fuels of Vietnamese origin; *) - chlorine content is 212 mg/kg
S = "- "stands for an sulphur content below detection limit

If no sulphur is in fuels the chlorine emission can be limited by feeding Ca-additives, e.g. CaO or $CaCO_3$ (Steinbrecht, 2008[a)]).

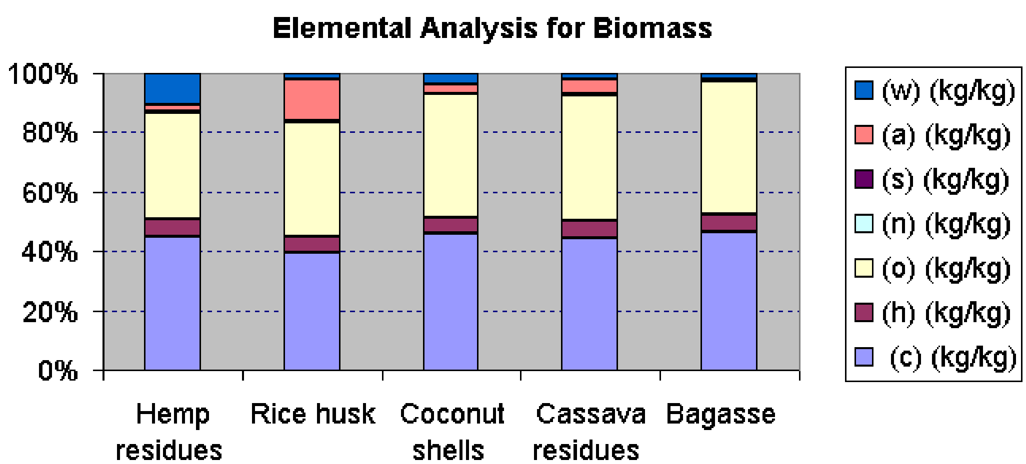


Fig.2. A comparison between the chemical compositions of different fuels

### 2.2 Presentation of the Experimental Plant

Figure 3 shows the technological flow sheet of SFBC and its auxiliary equipment mounted at the CEE at the University of Rostock, Germany. This system needs quartz sand as inertial material to realize clean SFBC combustion. The combustion air is supplied by roots blower and can be supplied into the reactor either directly or pre-heated by heat exchangers.

There is the possibility of the use of different fuels (gas, liquid, solid or mixtures) with different properties within the SFBC. Their particular different fuel properties need to use adequate equipment in the system. There are two screw feeders: solid fuel screw feeder and additive screw feeder. The solid fuel screw is controlled by a PI-type governor which is connected with the main computer.

The additive screw feeder can be used to transfer not only bed material but also different additives such as limestone or urea and fuels. Additionally there are two pump-systems which can supply liquid fuel: one for low viscous fuel (e.g. bio-diesel product) and another one for high viscous fuel (sewage sludge).

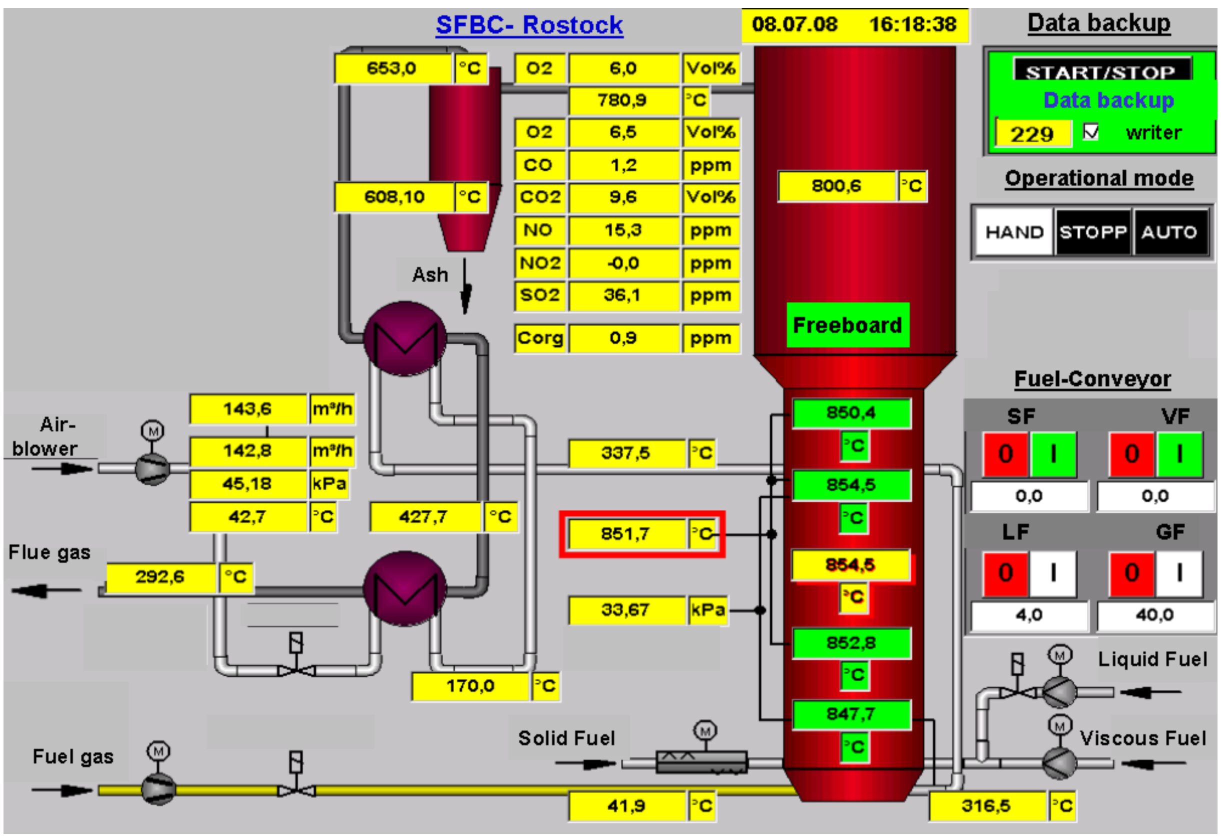


Fig. 3. The technological flow sheet of SFBC at the Chair of Environmental Engineering, University of Rostock, Germany (Steinbrecht, 2008[b)])

SF- Solid Fuel, VF- Viscous Fuel, LF- Liquid Fuel, GF- Gas Fuel

The system is equipped with great number of valves (either automatically or manually driven), thermocouples, flow meters and pressure gauges. Their entire outgoing signals are collected and then transmitted to the main computer. After that, they are noticed by special software made in the CEE. This software transfers the signals to the main computer. The main computer transmits signals to two monitors: major monitor (usually used by an operator to review different data and to manipulate the system) and minor monitor (which is always used to show a scheme of the system with actually measured signals). They show on-line changing parameters such as temperature of the bed, temperature of the freeboard, volume flow of air and fuel etc. (Fig. 3).

The system is equipped with three special tools for gas analysis (Fig. 4). The first is called 'ZIROX', giving on-line signals about the oxygen partial pressure (converted to concentration) in the humid flue gases. The second tool analyzes and measures the concentrations of exhaust emissions in the dried flue gas, such as oxygen ($O_{2dry}$), carbon monoxide (CO), carbon dioxide ($CO_2$), nitric oxide (NO), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$) and organic carbon compounds ($C_{org}$) (Fig. 3 & Fig. 4). The third system (coupling of gas-chromatograph and mass-selective detector) enables to find the kind and concentration of further organic pollutants.

Fig. 4. The systems for measurements of gas components in flue gas and for gas analyzes at the Chair of Environmental Engineering, University of Rostock, Germany

Like that, the experiments have been done with the plant SFBC-400 (Fig. 3). Fuels like gas, liquid, solid or the mixtures of them are available to be tested with this plant. The test parameters of the combustion process were adjusted by a process computer.

## 3. RESULTS AND DISCUSSION

The test run, carried out with the biomass fuel Hemp residues, lead to the following conclusions. The Fluidizing Bed Combustor (FBC) is suitable equipment for burning biomass. The Hemp residues are pressed to briquettes (Fig. 1) to realize a reliable fuel energy density. In this way prepared the Hemp residues can safely be fed by a screw feeder. This treatment is not needed for extraction coconut shells, cassava residues, bagasse, but it is also needed for rice husk firing (Fig. 1). This fact shows the necessity of an adaptation of the fuel delivering system to the focussed fuel, and the integration of a pre-processing step for the fuel respectively, while realizing an industrial plant.

The important process parameters during the tests were kept approximately constant. All operating process for the tests was chosen in accordance with the know-how of CEE and after a careful discussion. Table 4 and Fig. 5 show the parameters and results of the experiment.

Table. 4. Parameters and results of the experiment on 05.07.2006 tests Hemp residues

| | | | |
|---|---|---|---|
| Date | | yy.mm.dd | 06.07.05 |
| Measurement start | | hh:mm | 15:34 |
| Measurement end | | hh:mm | 16:06 |
| Duration | | min | 32 |
| Fuel | | | Hemp residues |
| Operating Parameters | | | |
| Name | Symbol | Unit | value |
| Volume of Combustion air | $V'_{Air}$ | $m^3/h$ | 134.1 |
| Fuel flow rate | $m'_{Fuel}$ | kg/h | 13.94 |
| Fuel capacity | $Q'_{Fuel}$ | kW | 63 |
| Combustion capacity | $Q'_{Combustion}$ | kW | 65 |
| Rated output (flue gas) | $Q'_{Flue\ gas}$ | kW | 37 |
| Fluidized bed temperature | $T_{FB}$ | °C | 793.7 |
| Freeboard temperature | $T_{Freeboard}$ | °C | 746.2 |
| Temperature of combustion air | $T_{combustion\ air}$ | °C | 53 |
| Humid oxygen | $O_{2\ humid}$ | Vol. % | 11.4 |
| Dry oxygen | $O_{2\ dry}$ | Vol. % | 12.6 |
| Emissions | | | |
| Carbon dioxide | $CO_2$ | Vol. % | 7.7 |
| Maximum Carbon dioxide | $CO_{2\ max}$ | Vol. % | 19.2 |
| Total organic carbon | $C_{org}$ | mg/m³(N) | - |
| Carbon monoxide (with $O_{2\ Basis}$ = 11.0 Vol. %) | CO (11% $O_2$) | mg/m³(N) | 11 |
| Nitrogen oxides (with $O_{2\ Basis}$ = 11.0 Vol. %) | $NO_x$ (11% $O_2$) | mg/m³(N) | 320 |
| Sulfur dioxide (with $O_{2\ Basis}$ = 11.0 Vol. %) | $SO_2$ (11% $O_2$) | mg/m³(N) | 4 |

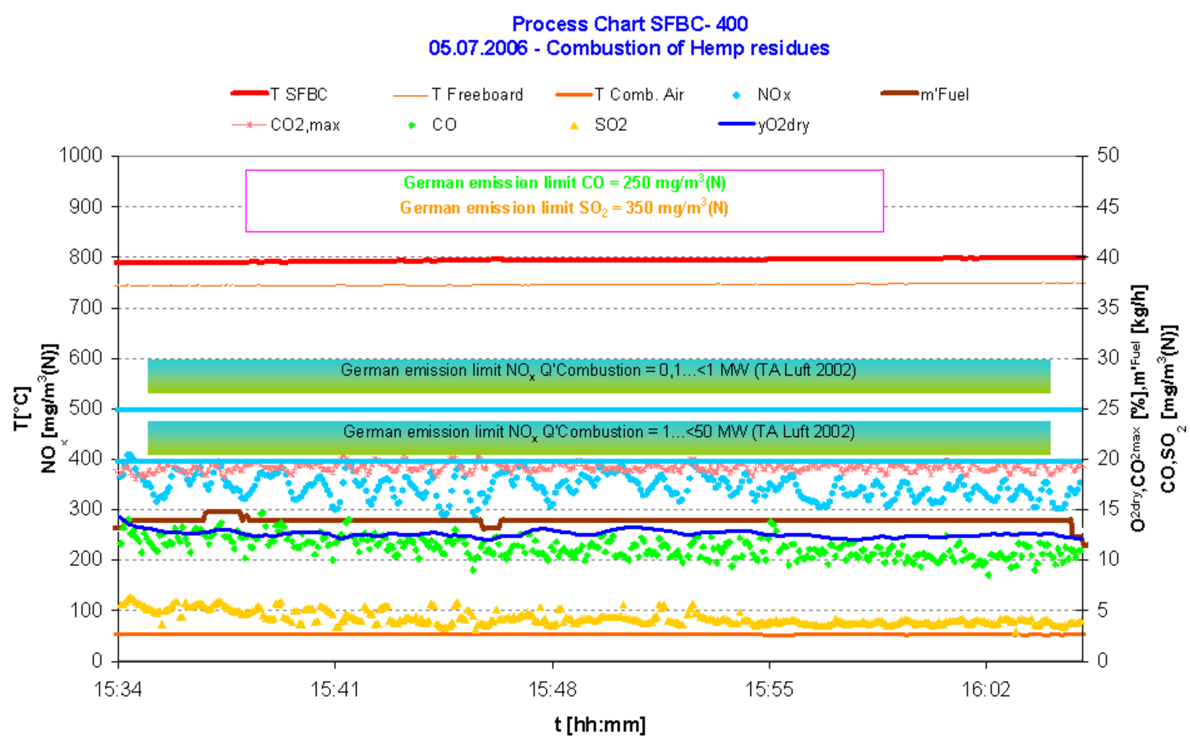


Fig. 5. Process chart of the test run

The ash-melting-problem can be faced with the decrease of the bed temperature below the critical limit. Otherwise the molten compounds lead to agglomeration and finally terminate the fluidized bed. The Hemp residues test run (Fig. 5) shows that a clean combustion is possible even below 800° C. This can be verified by the very low concentrations of carbon monoxide (CO) and the sum parameter $C_{org}$ (gaseous hydrocarbons) collected during the test run (Table. 4 and Fig. 5). Thus a steady-going and stable combustion with an energy-closed fuel conversion can be achieved in the combustions chamber.

The fuel-related acid emissions sulfur dioxides ($SO_x$) and hydrogen chloride (HCl) can procedural easily be abated by the additive process. Therefore limestone is applied to the reactor. This additive will react with the $SO_x$ and HCl to harmless products and leave the combustion chamber over the freeboard together with flue gas and fuel ash. Typically the dust mix is separated with a mechanic precipitator (bag house filter) to keep dust emissions within the prescribed limits. Several methods are known at the CEE to minimize nitrogen oxides in the flue gas. Generally suited are the methods of minimizing of oxygen concentration in the flue gas by using a fluidizing bed cooler or alternatively flue gas recirculation and the Selective Non-Catalytic Reduction (SNCR) with the reagent urea or ammonia solution. The choice of the measure depends on the height of the emission, the necessary level of abatement, the conception of the energy recovery, as well as the required legal limits and the economy of the plant.

The results of exhaust emissions after the investigations show in Figure 6. The concentration of exhaust emissions are based on the comparison with German emission limit (with concentration of $O_{2dry}$ = 11 Vol. %).

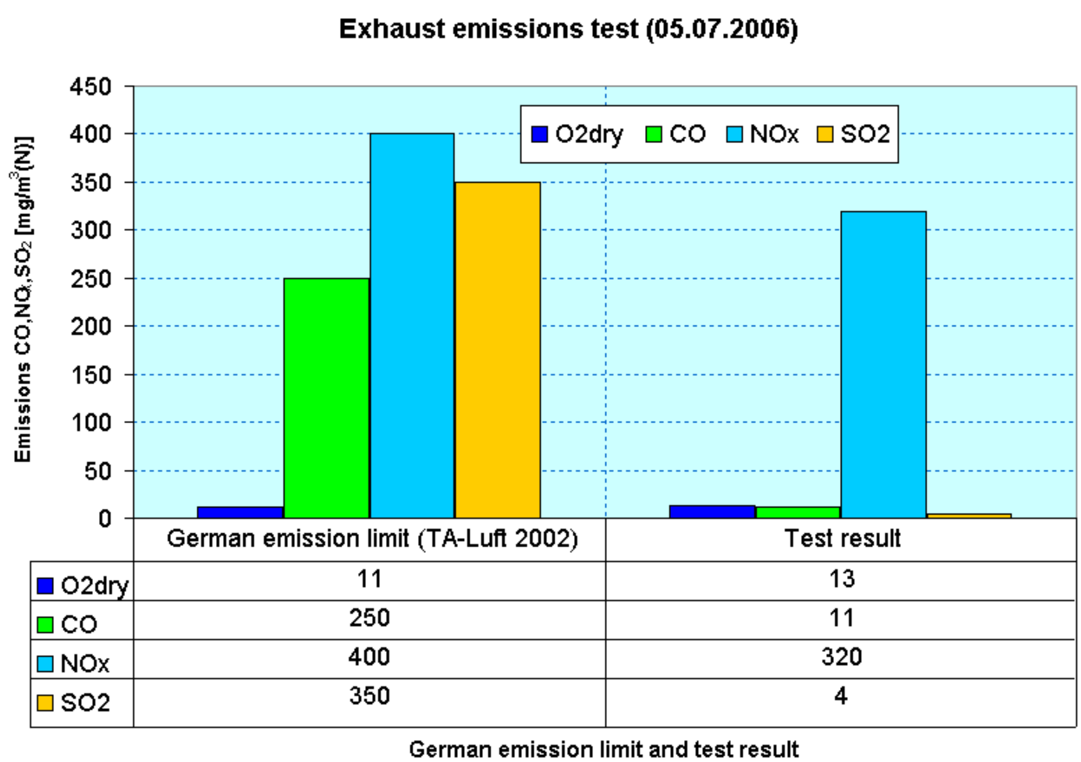


Fig. 6. Emission of Exhaust in comparison with the German emission limit (TA Luft 2002), (with $O_{2\ Basis}$ = 11.0 Vol. %)

Figure 6 shows, the concentration of $NO_x$ was smaller than the German emission limit (TA Luft 2002), (Limit of TA Luft 2002 is 400 mg/m$^3$ (N) flue gas, with $O_{2dry}$ = 11 Vol. %). The relative high $NO_x$ concentration appears because of the relatively high oxygen concentration during the combustion process. It can be minimized if the oxygen concentration is reduced, e.g. by heat-decoupling from the bed or by recirculation of "cold" cleaned flue gases. Particular, the concentrations of CO-emission and $SO_2$-emission were remarkably lower/smaller than the German emission limit, especially during the combustion of Hemp residues, indicating a clean burn out in the combustion chamber.

## 4. CONCLUSIONS

The combustion test of Hemp residues in SFBC was carried out at $T_{FB}$= 800$^o$ C and a fuel mass flow of 13.9 kg/h. This corresponds to fuel primary energy of 61 kW. Real SFBC plants are able to generate much higher power, e.g. 1.0 MW … 5.0 MW, or even more.

Experimental results have shown that the concentrations of CO, $NO_x$, and $SO_2$ in the flue gas are lower than the legal limits (TA- Luft, 2002, "Technische Anleitung zur Reinhaltung der Luft") especially in the region of small scale plants (power 0.1…<1.0 MW).

The flue gas heat energy after the SFBC reactor can be used for heating and other technological purposes. Typical example is drying of agricultural products.

The SFBC process is very useful for an application of biomass as a fuel, and can be used in Vietnam and other developing countries.

From the combustion tests, we judged the combustion of the Hemp residues by a stationary fluidized bed combustor is very suitable. Especially attention should be, in the future, focused on combined production of thermal and electric energy-CHP.

Obtained results showed that measured parameters of burning process affect emission like burning "**T**emperature", "**T**urbulence", and burning "**T**ime". These have strong effect on emission of CO, Corg, and $SO_2$ whereas $NO_x$ depends on characteristic of material, temperature and available oxygen concentration.

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