

TECHNICAL PAPER

# CARBONISATION OF SOLID RECOVERED FUEL (SRF) ON INDUSTRIAL SCALE

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## SRF FEEDSTOCK

Solid recovered Fuel (SRF) is a fluff material obtained from non-hazardous domestic and industrial waste. This waste has been made smaller, dried and inerts, ferro and non ferro has been removed as good as possible. Also chlorine containing materials has been removed with the best available technique of this moment.

The result is that SRF fluff mainly consists of wood, paper, card board, plastics, rubber and leather in variable composition, with about 1% chlorine, 0,2% sulphur, 7% water and 10% ash. It has been observed, that there is still a large spread on the composition and Net Calorific Value as received, (a.r.) of SRF.

### SRF carbonisation production process

Carbonisation tests on industrial scale in an indirect heated rotary furnace with a mixture up to 50 vol. % woodchips and 50 vol. % SRF show:

- The main problem appears in transporting the mixed raw material to the carbonisation reactor due to bridging and from the reactor to the grinding installation due to the presence of inerts, ferro and non ferro.
- Some plastics and rubber are not carbonised in a proper way and have still elastic properties. By that these parts could not be grinded after carbonisation in a proper way, which causes an increase in power consumption and eventually clogging.

This means modifications are needed to the present installation to avoid bridging problems of the mixed feedstock before carbonisation and transport and grinding problems of the carbonised material after carbonisation.

Besides, it has been observed:

- Emission measurements of the flue gases show a chlorine content far above the max. allowed value. This means only SRF with extreme low chlorine content (similar to wood) can be used for carbonisation or otherwise a flue gas cleaning is undoubtedly necessary.
- It is expected, that more than enough heat will be available for pre-drying and carbonisation. This heat is generated by incinerating the carbonisation process gases. This surplus of heat can be used for other useful applications.

## Carbonised SRF/woodchips product

- Ash content of the carbonised product will be > 10% and by that one of the main points of discussion with the application of this carbonised material.
- The chlorine content (can be up to 0,5%) and lead content (can be up to 500 mg/kg) will be a point of discussion. Laboratory tests have shown, that due to carbonisation organic chlorine is converted to an organic chlorine.
- Grinding and a hot water washing process after carbonisation can remove these chlorine salts up to 90%.
- The net calorific value (NCV a.r.) will be rather high (24 MJ/kg up to 28 MJ/kg) in spite of the rather high ash content.
- Small scale co-firing tests (about 30 tons) with grinded carbonised SRF product did not show a problem.
- Pelletizing tests with this carbonised SRF material have not been carried out.

### How to proceed with carbonisation of SRF?

- New tests with different kinds of SRF quality can only be done after bridging, transport and grinding problems have been solved by modifying the present carbonisation installation.
- Investigation should be started to find out which flue gas cleaning technique will be the best for the SRF carbonisation production process.
- Hot water washing process to remove chlorine salts and re-use of the washing water have to be developed more in detail.
- Application specific required product specification of carbonised SRF material and related problems need to drive decisions for further refined pre-processing steps and understand solutions space/technical feasibility.

## FEEDSTOCK FOR SRF CARBONISATION TESTING

During the tests, a mixture of wood chips and SRF (Solid Recovered Fuel) is used as raw material for carbonisation. SRF is obtained from crushing, drying and separating non-hazardous household and/or industrial waste (removal of inert, ferrous and non-ferrous as best as possible). SRF therefore is composed of various plastics, rubber, leather, wood, cardboard and paper and is supplied in the form of fluff. The bulk density on arrival was approx. 0.20 kg/m<sup>3</sup> (slightly compacted).

SRF feedstock has been characterised (see table 1: 12 different measurements of 12 different production batches). The large differences between the minimum and maximum measured value (therefore a large spread) are striking.

Variable	Unit	#	Avg.	St. Dev.	Min.	Q1	median	Q3	Max.
Dry matter	%	12	93.2	3.21	87.5	91.0	93.8	96.1	96.5
Ash residue	% DS	12	10.6	5.2	1.1	10.0	10.7	13.1	20.0
NCV (a.r.)	KJ/kg	12	20823	3990	12987	19740	21150	23270	26191
Chlorine total	mg/kg DS	12	8024	6644	500	4088	5915	10388	20200
Sulphur	mg/kg DS	12	1857	829	300	1735	2115	2315	2840

Table 1: SRF feedstock characterisation

## SRF CARBONISATION PRODUCTION PROCESS

### Test 1

SRF (water content approx. 12%) was pre-mixed with pre-dried wood chips (water content < 10%). This pre-dried mixture was fed into the carbonisation reactor without further pre-treatment. Two mixing ratios were tested: one part SRF with one part wood chips (so in volume 1:1) and one part SRF with five parts wood chips (so in volume 1:5).

In both cases, many problems occurred in the path after the carbonisation reactor. The presence of larger pieces of inert (stone, glass, ceramics), ferrous and non-ferrous (stainless steel, copper, aluminium) in the raw material SRF caused problems during transport (particularly with screw conveyors and Zellrad locks) and grinding. In addition, not all plastic parts of the SRF were carbonised to the same extent and therefore still showed elastic properties. These parts could not be ground properly and led to an increase in power consumption during grinding and ultimately to clogging.

### Test 2

The mixing of SRF with wood chips took place in the preliminary phase, in-line with the carbonisation process. Wood chips were fed through the belt dryer and the SRF through a separate feed hopper. Mixing took place just before the reactor. Different mixing ratios have been made for this test. Started with approx. 10 vol. % addition of SRF and this was increased stepwise to approx. 50 vol. %.

In addition to the problems already observed in test 1, bridging was now also observed in the feed hopper for SRF and feed bunker of the reactor.

The SRF feedstock contained quite a lot of iron (approx. 1%). As a result, the iron separators (magnets) had to be cleaned regularly. The grinding installation was also regularly cleaned to prevent clogging due to incorrectly carbonised plastics/rubbers and non-ferrous components.

During the test, a flue gas emission measurement also took place at the time of approximately 25% addition of SRF was being carbonised. With carbonisation of a total of 2 tons/h of wood chips with 25% addition of SRF (chlorine content of SRF feedstock up to approx. 2.0%), the emission of gaseous chlorides amounted to approx. 600 mg/Nm<sup>3</sup> of dry flue gas (chlorine emission: 5.68 kg/h).

When carbonising 2 tons/h of dry wood chips (chlorine content of wood chips approx. 0.01%), the emission of gaseous chlorides is on average approx. 15 mg/Nm<sup>3</sup> dry flue gas with 14% O<sub>2</sub> (chlorine emission: 0.12 kg/h). So by adding 25% SRF, the chlorine emission has increased by a factor of 47 and has risen far above the maximum permitted emission value (threshold half-hour average for chlorine 60 mg/Nm<sup>3</sup> for dry flue gas with 11% O<sub>2</sub>).

Summarized in table 2:

Feed wood chips (dry) with approx. 0.01% chlorine	Feed SRF (dry) with to approx. 2.0% chlorine	Chlorine content in dry flue gas with 14% O <sub>2</sub>	Amount of dry flue gas with 14% O <sub>2</sub>	Chlorine emission
2000 kg/h	---	15 mg/Nm <sup>3</sup>	7600 Nm <sup>3</sup> /h	0,12 kg/h
1500 kg/h	500 kg/h	600 mg/Nm <sup>3</sup>	9470 Nm <sup>3</sup> /h	5,68 kg/h

Table 2: Flue gas emissions during carbonisation

For SRF, the above is based on one measurement and for this reason the stated results should only be seen as indicative. It can be concluded, however, that when processing SRF, flue gas cleaning (for HCl removal) will be absolutely necessary before the flue gases can be discharged to the outside air.

## MASS/ENERGY BALANCE

If a mixture of SRF (fluff) with wood chips is carbonised (mixing ratio 50 mass % SRF and 50 mass % wood chips, intended mass on ash and anhydrous basis), then the following mass and energy balance applies:

### Wood chips

Input: 2650 kg/h (d.a.f.) with a GCV of 20 MJ/kg (d.a.f.). So in total  $(2650 \times 20)/3600 = 14.7$  MW.

Output: 1500 kg/h (d.a.f.) with a GCV of 25 MJ/kg (d.a.f.). So in total  $(1500 \times 25)/3600 = 10.4$  MW.

The conversion (residual solid after carbonisation) is therefore  $1500/2650 = 0.57$  in this case.

### SRF

Input: 2650 kg/h (d.a.f.) with a GCV of 27 MJ/kg (d.a.f.). So in total  $(2650 \times 27)/3600 = 19.9$  MW.

Output: 1722 kg/h (d.a.f.) with a GCV of 30 MJ/kg (d.a.f.). So in total  $(1722 \times 30)/3600 = 14.4$  MW.

The conversion (residual solid after carbonisation) is therefore in this case  $1722/2650 = 0.65$  and is therefore not equal to that of the wood chips under the same carbonisation conditions.

### Mixture of wood chips/SRF

Input =  $14.7 + 19.9 = 34.6$  MW,

Output =  $10.4 + 14.4 = 24.8$  MW.

The difference between input and output is 9.8 MW.

This is therefore in  $(2650 - 1500) + (2650 - 1722) = 2078$  kg process gas and is released when these gases are burned in the form of hot flue gases.

This 9.8 MW is used as follows, namely:

- approx. 1 MW to keep the temperature of the carbonisation reactor.
- approx. 3 MW to evaporate 2500 kg of water from the wood chips (45% water) and SRF (10% water).
- approx. 2 MW disappears with the warm flue gases (approx. 150°C) through the chimney.
- This leaves  $9.8 - 1 - 3 - 2 = 3.8$  MW and can possibly be used for other useful applications.

The above mass/energy balance is mainly based on a theoretical approach and can therefore not really be tested in practice. This can only be done in long-running carbonisation tests with SRF.

## THE CARBONISED SRF PRODUCT

SRF feedstock contains a high ash content (approx. 10% on average). This content increases further with carbonisation, because part of the SRF is converted into gas and the ash originally present remains behind in the product. The ash content in the product, in addition to the ash content in the raw material, is therefore also determined by the degree of admixture and the extent to which it is carbonised (conversion value). For example, a 50% addition of SRF to wood chips and a carbonisation conversion of 60% (residual mass after carbonisation) will quickly lead to an ash content of over 10%. The ash will consist of approximately 75% Ca and Si compounds and approximately 25% of Fe, Al, K, Na and Mg compounds.

Other elements like lead (Pb: approx. 500 mg/kg) and chlorine (Cl: approx. 0.3%) are the most problematic at 50% admixture with SRF. These are clearly higher than the maximum permissible values indicated by energy products (Pb max. 50 mg/kg; Cl max. 0.1%).

Despite the high ash content, the lower heating value (NCV a.r.) is at a reasonable level. Values of 24 MJ/kg to 28 MJ/kg should be considered here and are determined by the amount of SRF added and the degree of carbonisation (conversion value).

The carbonised product (approx. 50 vol. % SRF added to the wood chips before carbonising) was delivered in a ground state (powder) to a customer and processed there without any problems to produce the required industrial heat.

## DISCUSSION

There is a wide spread for some important SRF characteristics like moisture content and ash, chlorine and sulphur content which will have consequences on the carbonisation process and the product quality. In addition, it has been established that, despite the separation during the production of SRF, there is still inert, ferrous and non-ferrous in the SRF.

When carbonising an SRF/wood chips mixture, a robust roller crusher with sieve must be placed behind the cooler, i.e. immediately after the carbonisation reactor. The parts that do not appear to be breakable must be removed from the product flow as quickly as possible. The presence of larger pieces of inert (stone, glass, ceramics), ferrous and non-ferrous (stainless steel, copper, aluminium) cause problems during transport (particularly with screws and locks) and grinding. Plastics, which are not properly carbonised, remain elastic and this leads to clogging of the milling plant. The residual material flow resulting from the grinding/sieve step will therefore consist of inert, ferrous, non-ferrous, elastomers and a quantity of properly carbonised material. A useful application must still be found for this residual material flow. It is unclear how large this flow will be (will be strongly determined by the quality of the raw material SRF obtained).

The presence of chlorine in the SRF leads to formation of chloride gas during carbonisation. Chlorides partly remain in the carbonised material and partly are discharged with the carbonisation process gases to the afterburner and thus ultimately emitted with the flue gases to the outside air. Chlorides in the carbonisation installation lead to corrosion and thus a shortened lifespan of the installation. Besides, the applicable standard of max. permitted chlorine emission is exceeded. Chlorides in the carbonisation product could cause corrosion and also emission problems in the installation at the customer.

The aim is therefore to process SRF with the lowest possible chlorine content. SRF is currently available with a Cl content of < 1.0%. Some SRF suppliers claim to be able to supply SRF with a Cl content of about 0.1%. However, this is considerably more expensive and the chlorine content is probably still not low enough to meet the applicable standard of maximum permitted chlorine emission in the flue gases of the carbonisation process. In any case, a flue gas cleaning during the carbonisation process remains necessary.

In order to meet the maximum permitted chlorine requirement of the carbonised product processor, SRF with a low chlorine content must be used or the other option is to remove the chlorides from the product after carbonisation using electrolysis or a washing process.

It has been found that during the carbonisation process the organic chlorine present partly disappears with the process gas in the flue gases. The rest is converted into chlorides and remains in the carbonised material. The chlorine present in the chloride form can then be removed for more than 90% by washing the carbonised product with hot water. The chlorides present in this process end up in the washing water.

In 2006 and 2007, this washing process was extensively studied in laboratory scale in collaboration with the Flemish research Institute VITO. A global assessment was made about how this washing process could possibly be carried out on an industrial scale. However, more research/ tests are still necessary to determine what the technical implementation on an industrial scale of the washing process and processing of the used washing water should look like.

The washing process and subsequent drying of the wet washed-out and processing of the used washing water will require energy (heat). The mass energy balance shows that heat is still available and can therefore be used for this purpose.

Whether the available energy will be sufficient is strongly determined by the chosen techniques for the washing and drying process of the carbonised material and the processing of the used washing water.