Converting Low-Value Feedstock Into Energy: Recent Developments in Gasifying Paper Rejects, RDF and MBM at 5 KWTH, 25 KWTH and 80 MWTH Scale

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June 2015
ECN-M--15-029

CONVERTING LOW-VALUE FEEDSTOCK INTO ENERGY: RECENT DEVELOPMENTS IN GASIFYING PAPER REJECTS, RDF AND MBM AT 5 KW_{TH}, 25 KW_{TH} AND 80 MW_{TH} SCALE

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ABSTRACT: The aim of decreasing the production cost of renewable electricity is expected to reduce the governmental subsidies for (clean, relatively expensive) biomass supply in the future. This makes necessary to find alternative (cheaper, yet troublesome) low-value feedstock. The main technical challenges associated to these fuels are fouling, deposition and corrosion in the gas cooling sections of the plant. The adaptation and optimization of indirect co-firing technology for low-value, difficult feedstock can reduce costs, thus widening the application market.

In this work, several low-value, troublesome feedstock (paper rejects, refuse-derived fuel RDF, and meat and bone meal MBM) have been tested both at laboratory scale (5 kW_{th} BFB and 25 kW_{th} MILENA facilities at ECN) and commercial scale (80 MW_{th} CFB gasifier at the Essent's Amer 9 power plant). The tests have given insight on the required adaptation of the gasifier, the gas cleaning section and the boiler when operating with these specific feedstock. Focus has been placed on the fate and distribution of troublesome compounds (alkalis, chlorine, sulfur, heavy metals).

The lab-scale results have shown that a decrease in gasification temperature from 850°C to 750°C leads to a trade-off between fuel conversion and release of contaminants to the gas phase. Furthermore, a different quantitative distribution of fouling elements in the solid- and gas phase has been observed. On the other hand, the concentration of Cl and NH_4^+ in producer gas is similar from either MILENA indirect gasification or direct BFB gasification. Lastly, results of wood/RDF co-gasification at the 80 MW_{th} CFB gasifier have shown that the gas cooler fouling, the main concern issue, can be reduced by decreasing the gasification temperature, thus leading to higher plant availability.

KEYWORDS: co-gasification, corrosion, deposition, fouling, cofiring, low-value feedstock, meat and bone meal, paper rejects, RDF, residues, waste.

1 INTRODUCTION

Power, an essential part of modern society, is currently generated mainly from fossil fuels like oil, natural gas and coal. However, an increasing number of countries are setting objectives and obligations to replace part of their fossil fuel consumption with (low-value) biomass and waste to reduce CO_2 emissions. The aim of decreasing the production cost of renewable electricity is expected to reduce the governmental subsidies for (clean, relatively expensive) biomass supply in the future. This makes necessary to find alternative (cheaper, yet troublesome) low-value feedstock. The main technical challenges associated to these fuels are fouling and deposition in the gas cooling sections of the plant.

A combination of a gasifier and a boiler (i.e. indirect co-firing) can be used to efficiently convert difficult feedstock into heat and power. The gasifier firstly transforms the solid feedstock into a relatively easier gaseous fuel, thus acting as a fuel pre-treatment. The adaptation and optimization of the technology for low-value, difficult feedstock can reduce costs, thus widening the application market.

Within the framework of a joint project between ECN (research institute), RWE Essent (utilities company), HoSt (gasifier manufacturer) and NEM (boiler manufacturer), several low-value, troublesome feedstock (paper rejects, refuse-derived fuel RDF, and meat and bone meal MBM) have been tested both at laboratory scale (5 kW_{th} BFB and 25 kW_{th} MILENA facilities at ECN) and commercial scale (80 MW_{th} CFB gasifier at the Essent's Amer 9 power plant). The experiments have given insight on the required adaptation of the gasifier, the gas cleaning section and the boiler when operating with these specific feedstock.

With this background, the main objective of this work is the assessment of the effect of the temperature (main operating parameter) on the gasification of low-value fuels (paper rejects, meat and bone meal, and RDF) at lab-scale (5 kW_{th} BFB, 25 kW_{th} MILENA) and the evaluation of the effect of replacing part of the fuel (wood) with a low-value feedstock (RDF) in a commercial-scale gasifier (80 MW_{th}). This paper, which focuses on the fate and distribution of troublesome compounds (alkalis, chlorine, sulfur, heavy metals), will present the most relevant results obtained during the project.

2 EXPERIMENTAL SECTION

2.1 Feedstock tested

Based on a prior selection taking into account different factors (cost, availability and logistics, tendency to fouling, agglomeration and corrosion, emissions, ash quality and required pre-treatment), three different low-value fuels have been selected for the project:

- Paper rejects supplied by ESKA (cardboard manufacturer). The raw feedstock consists of shredded material (mainly plastic, paper, fabrics, and metals), and has a large moisture content (approximately 40-60% wt. wet basis).

- Refuse-derived fuel (RDF) supplied by RWE Essent (energy company). This feedstock was tested both at lab- and commercial-scale, and is largely composed of plastics, paper and metals, similarly to paper rejects.
- Meat and bone meal (MBM): classified as category 3 (low-risk material), the tested MBM is composed of slaughterhouse waste from animals allocated for human consumption. It is received as a dry, powder-like material.

The characterization of the tested feedstock is summarized in Table I and Figure 1. As can be seen, all the feedstock contain a large content of ash. Meat and bone meal has a high content in calcium and phosphorus, whereas RDF and paper rejects contain significant concentrations of chlorine, aluminum, calcium, iron, copper and silica.

Table I: Characterization of the low-value feedstock tested.

		MBM	Paper rejects	RDF
Ash 550	(% wt. dry)	26	14	24
Volatile matter	(% wt. dry)	65	75	67
HHV	(MJ/kg, dry)	18.8	26.3	22.6
C	(% wt. dry)	42	57	49
H	(% wt. dry)	6	8.1	6.7
N	(% wt. dry)	8.6	0.3	0.95
O	(% wt. dry)	19	23	23
S	(mg/kg dry)	3800	894	2933
Cl	(mg/kg dry)	5000	18014	14381

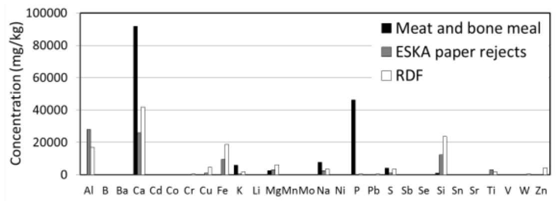


Figure 1: ICP analysis of the low-value feedstock tested.

Paper rejects and RDF are supplied as bulky, fluffy materials with a high moisture content and containing pieces (metals, stones) that can risk the operation of the different laboratory equipment (pelletization, grinding, and feeding systems). Therefore, a pretreatment step of the fuels was necessary in order to allow reliable and safe operating conditions. Firstly, manual sorting of the material was carried out by removing some hard plastic particles and (almost) all metals. Then, the material was pelletized twice with a 8 mm dye. During this process, the material was largely dried. The first pellets were air dried and pelletized again for six times using a 4-mm dye. The moisture content of the 4-mm pellets produced was ~ 35%. The pellets were air dried again, and grinded to 2-3 mm particles which were suitable for feeding in the laboratory. Representative samples of the grinded material was taken for analysis.

2.2 Experimental facilities

2.2.1 5 kW_{th} BFB, ECN

An experimental plan for the study of the effect of gasification temperature on the performance of the selected low-value feedstock was carried out at the 5 kW_{th} BFB facility located at the ECN laboratories (Figure 2). As can be seen, the outlet gas line includes a cyclone for bulk dust capture, a bypass for the sampling of dust/soot and gas phase, and sampling points for SPA tar measurement and micro-GC analysis. Dust/soot was collected in a Soxhlet filter heated up at 400°C. Furthermore, a deposition probe (stainless steel, 20 mm x 20 mm x 6 mm) was implemented on the gasifier freeboard for the study of fouling and deposition processes. Via water cooling, the temperature of the deposition probe was kept at 250-350°C. The metal probes collected after each experiment were subjected to SEM/EDX analyses.

The lab-scale gasification tests were performed using air/steam mixtures as gasification agent. The steam added to the gasifier aims at simulating the initial moisture content of the different fuels. For each fuel, tests at 750°C and 850°C (also at 700°C for paper rejects) were carried out. Quartz sand (particle size above 0.25 mm) was used in all cases as bed material. In all tests, approximately 0.3 kg/h feedstock was fed to the gasifier.

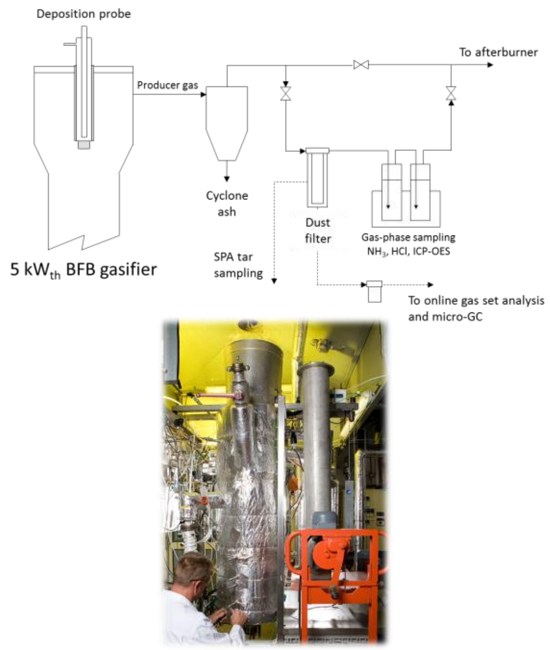


Figure 2: 5 kW_{th} BFB facility at ECN.

Dry producer gas composition (CO, CO_2, H_2, CH_4, C_2H_2, C_2H_4, C_2H_6, H_2S, COS, and N_2) was determined online by micro-GC analysis. Tar content and composition was measured using Solid Phase Adsorption (SPA) analysis. This paper focuses on the distribution of troublesome compounds (alkalis, chlorine, sulfur, heavy metals). Therefore, the dust filter, the deposition probe, the cyclone ash and the final bed material were weighed before and after the test and sampled for further chemical analysis. A slipstream of producer gas was bubbled through a 1 M HNO_3 solvent for sampling and further determination of the gas phase composition. From the resulting liquid solution, the NH_3 content was determined by Ammonia Flow Injection Analysis, and the HCl content was analyzed via Ion Chromatography. The solution, was also analyzed via Inductively-coupled Plasma Optical Emission Spectroscopy (ICP-OES), as well as the cyclone ash, the dust collected in the filter and the final bed material, for the determination of the distribution of the elements (including alkali and heavy metal content) in each product fraction.

2.2.2 25 kW_{th} MILENA gasifier, ECN

MILENA is an indirect gasification technology developed by ECN. The MILENA gasifier is composed of a riser, where the fast devolatilization/gasification of biomass takes place, and a BFB combustor, where the remaining char is oxidized. In the settling chamber, solids (char and bed material) are separated from the producer gas and recirculated to the combustor via the downcomer. Heat is transferred between the combustor and the riser through the circulation of bed material. The main advantages of MILENA include the total conversion of the fuel and the production of a N_2-free gas without the need for an air separation unit, in an integrated design [1].

The performance of direct BFB gasification and indirect gasification in terms of formation of contaminants has been compared. With this purpose, an experimental test using paper rejects as feedstock has been performed at the 25 kW_{th} MILENA gasifier located at the ECN laboratories. A schematic layout of the unit is shown in Figure 3.

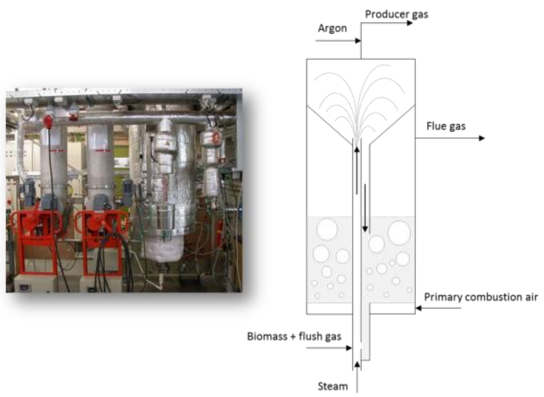


Figure 3: 25 kW_{th} MILENA gasifier at ECN.

The gasification test was carried out using 3.5 kg/h paper rejects, and Austrian olivine as bed material. The riser temperature was kept at ~730°C. 100 NL/min primary air was fed to the BFB combustor. Producer gas composition, tar concentration/composition, and gas phase composition have been measured and analyzed using a similar procedure as described in Section 2.2.1. However, no deposition probe was inserted in the gasifier.

2.2.3 80 MW_{th} CFB gasifier at the Amer 9 plant, Geertruidenberg

The Amer 9 power plant (Figure 4), owned by RWE Essent, has an electricity output of 640 MW_e, mainly produced by coal. In the boiler, producer gas from biomass/waste gasification is co-fired. Approximately 33 MW_e is produced from biomass. The standard feedstock used in the gasifier is demolition wood.

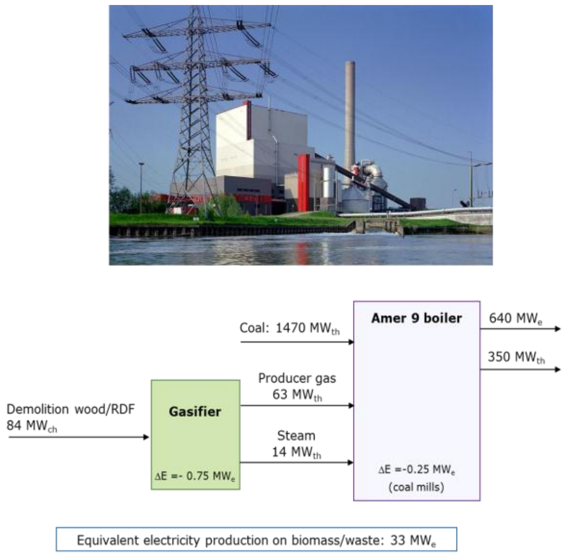


Figure 4: 80 MW_{th} CFB gasifier in Amercentrale 9 Essent plant, Geertruidenberg, Netherlands.

3. 5 KW_{th} BFB GASIFICATION OF MBM, PAPER REJECTS AND RDF

3.1 Tar production and composition

Tars produced during gasification have a strong influence on the fouling properties of the producer gas and thus on the downstream equipment like gas coolers. In this work, the ECN classification, based on the structure and solubility of tars, was used for the determination of tar composition. The results are summarized in Figure 5**.** As can be seen, class 2 and 3 tars decrease at temperatures above 750°C, whereas class 4 and 5 (PAHs, most troublesome tars) increase with gasification temperature regardless of the feedstock tested. Moreover, in the case of paper rejects, it can be observed that by decreasing the temperature from 750°C to 700°C, the concentration of total tar is dramatically increased. Therefore, high gasification temperatures leads to a lower total tar production (directly related to higher fuel conversion levels), but with a higher fraction of heavy, troublesome tars. On the contrary, low-temperature gasification boosts the total tar production (thus indicating a lower fuel conversion degree), but with a lower fraction of (heavy) class 4 and 5 tars. Thus, gasification temperatures ~750°C lead to a trade-off between tar production (i.e. fuel conversion) and tar composition (i.e. tar dew point). Both RDF and paper rejects contain a large fraction of plastics that partially breakdown during gasification into aromatic compounds that can mature into PAHs. The large fraction of plastics might be the responsible for the significantly higher tar concentration of RDF and paper rejects compared with meat and bone meal. Figure 6 shows as an example the detailed composition of tars produced from paper rejects gasification. As can be seen, naphthalene and (o-xylene + styrene) are the most significant compounds detected in the tars. RDF gasification (not shown) leads to a similar tar composition.

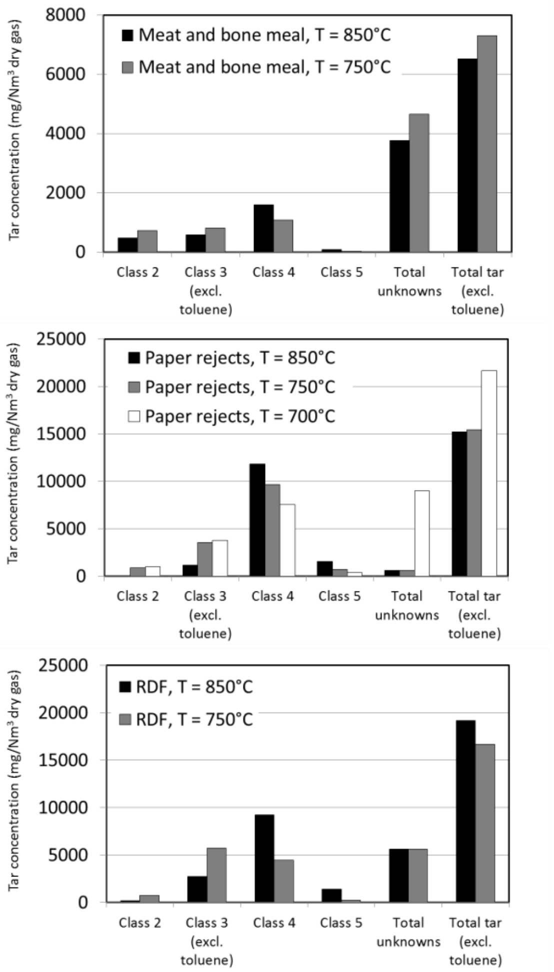


Figure 5: Effect of temperature on the distribution of tars for the three feedstock tested.

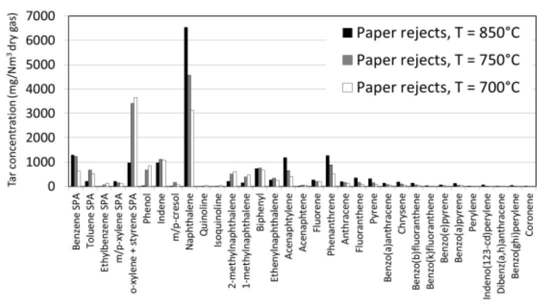
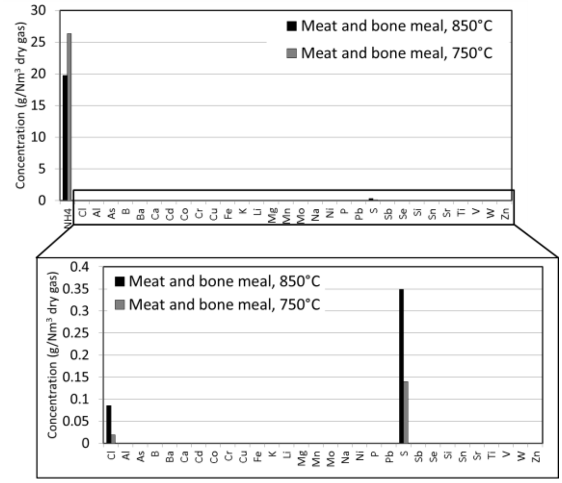


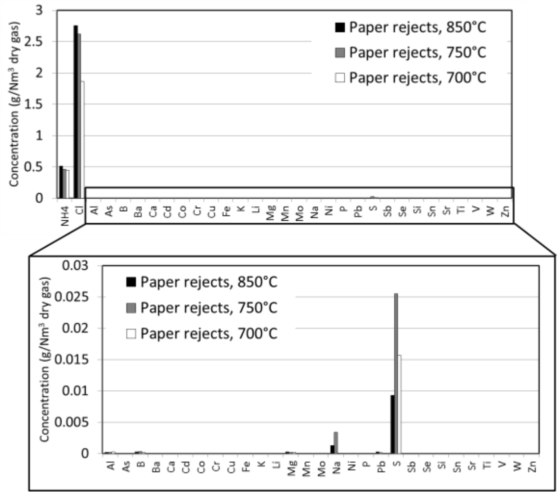
Figure 6: Composition of tars produced from paper rejects gasification.

3.2 Distribution of elements in gas phase, cyclone ash and filter dust

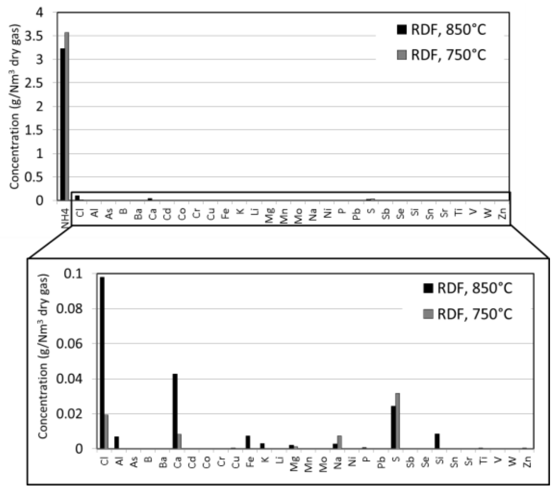
Figure 7 shows the gas phase composition of producer gas from MBM, paper rejects and RDF gasification. The composition was determined by ICP-OES analysis performed to the liquid solution resulting from the sampling of the gas.



(a)



(b)



(c)

Figure 7: Effect of temperature on the gas phase composition of producer gas: (a) MBM gasification; (b) Paper rejects gasification; (c) RDF gasification.

As can be observed in Figure 7, the most abundant compounds contained in the gas phase are NH_4^+ (which is due to the decomposition of NH_3 in the solution), chlorine and sulfur. Producer gas from MBM gasification contains mainly nitrogen (20-26 g/Nm^3), with small amounts of sulfur (0.15-0.35 g/Nm^3) and traces of chlorine (0.01 – 0.08 g/Nm^3). Producer gas from paper rejects gasification has the highest concentration of chlorine (1.8-2.7 g/Nm^3) in the gas phase, with low concentrations of nitrogen (~0.5 g/Nm^3) and sulfur (0.01 – 0.025 g/Nm^3). RDF gasification produces a gas with mainly nitrogen (3.2-3.6 g NH_4^+/Nm^3), minor concentrations of Cl (0.02– 0.1 g/Nm^3), Ca (0.01 – 0.04 g/Nm^3) and S (~ 0.03 g/Nm^3), besides traces of Al, Fe, K, Mg, Na and Si (< 0.01 g/Nm^3). In general, it can be seen that lower temperatures lead to decreased concentrations of chlorine released to the gas phase.

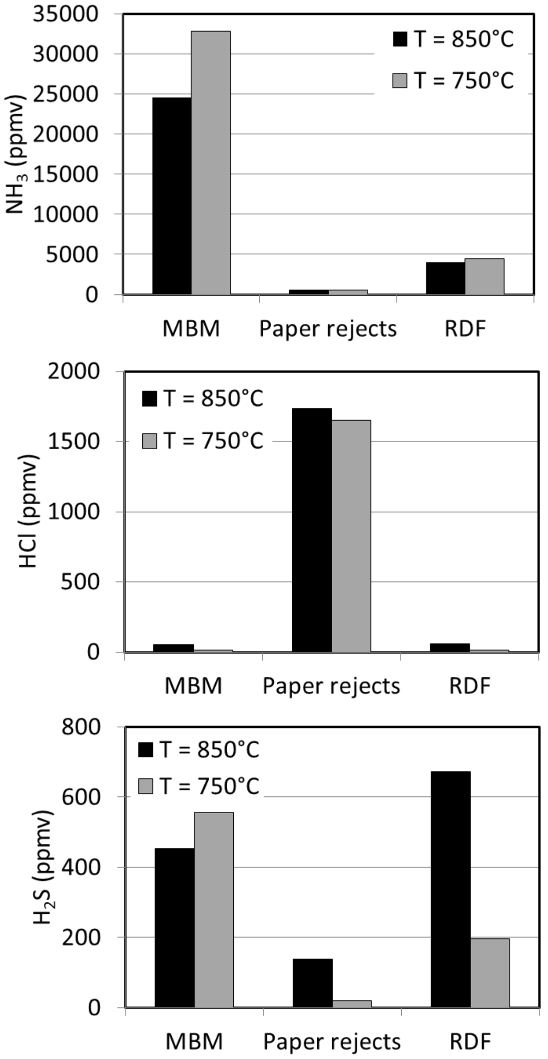


Figure 8: Effect of temperature and feedstock on NH_3, HCl and H_2S concentration in the dry-basis producer gas.

Figure 8 compares the concentration of H_2S (measured by micro-GC), NH_3 (analyzed via Ammonia Flow Injection Analysis applied to the liquid solution obtained from sampling of the slipstream of producer gas), and HCl (determined by ion chromatography performed on the same liquid solution sample). In all cases, the concentrations refer to dry gas. As can be seen, producer gas from MBM gasification contains by far the highest concentration of NH_3 (2.5-3.3% vol. dry) among the low-value feedstock tested, whereas the concentration of HCl (~1700 ppmv dry) is dramatically higher in producer gas from paper rejects gasification. On the contrary, paper rejects gasification leads to the lowest H_2S concentration among the feedstock tested. On the other hand, it can be seen that lower gasification temperatures promotes the production of NH_3 (this effect being particularly significant in the case of MBM), whereas lower temperatures decrease the HCl concentration of the producer gas. No clear trends have been found in the case of H_2S concentration. It is interesting to observe the dramatic difference in HCl concentration in the producer gas from paper rejects and RDF gasification despite the similar Cl concentration in both feedstock (Table I). The difference behind the different behavior of both feedstock might be on the different moisture content of the feedstock. As presented in Section 2.2.1, different steam flow rates were added to the gasifying air in order to simulate the inlet moisture content of the fuels. For this reason, 300 g/h steam was added in the paper rejects tests, compared to 70 g/h steam in RDF gasification. Steam promotes the hydrogen content of producer gas during gasification, and H_2 in turn is reported to react with chlorides to form HCl [2]. This implies that not only the gasification temperature, but also the inlet moisture content of the fuel can significantly influence the HCl formation in the process, and therefore the associated problems (deposition, corrosion, etc.). Thus, a smart process design (fuel pretreatment, gasification operating conditions, gas cleaning section) can significantly limit the technical problems associated to low-value feedstock.

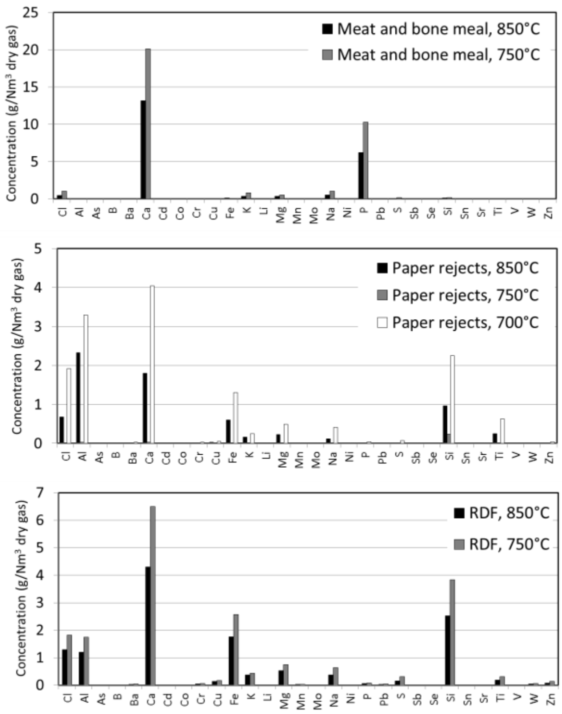


Figure 9: Effect of temperature on the cyclone ash composition for the three feedstock tested.

Figure 9 and Figure 10 display the results of concentration of elements in the cyclone ash and the dust collected in the filter, respectively. It must be emphasized that during the test performed at 750°C with paper rejects, clogging of the cyclone took place, which is responsible for the abnormal distribution of elements between the cyclone ash and the filter dust observed (no dust is retained in the cyclone, and thus very high dust concentrations are retained in the filter). As can be seen in Figure 9, lower gasification temperatures lead to higher concentration of elements retained in the cyclone ash. Fly ash from MBM gasification is rich mainly in Ca and P, with traces of Cl, K, Mg and Na. On the other hand, the composition of the cyclone ash from gasification of paper rejects and RDF is similar, with significant contents of Ca, Al, Si, Cl, Fe, and minor concentrations of K, Mg, Na and Ti.

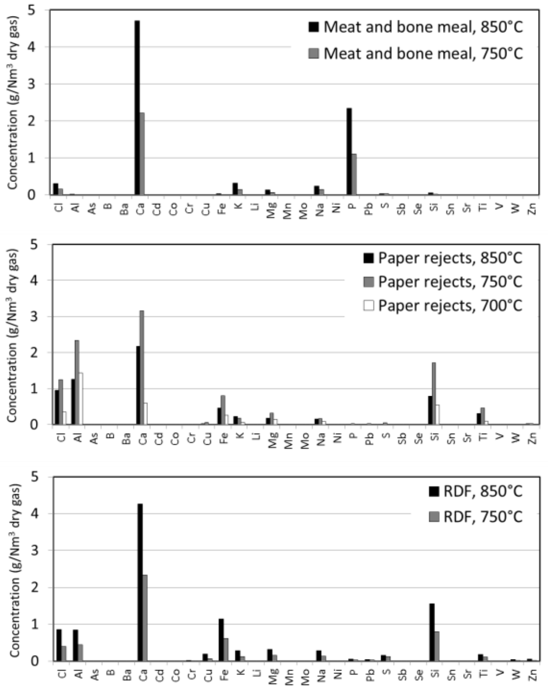


Figure 10: Effect of temperature on the filter dust composition for the three feedstock tested.

In Figure 10 it can be observed that the filter dust produced from MBM gasification contains mainly Ca (2.2 – 4.7 g/Nm^3 dry) and P (1.1 – 2.4 g/Nm^3 dry), with less significant concentrations of chlorine, potassium and sodium (< 0.3 g/Nm^3 dry). The filter dust produced in paper rejects- and RDF gasification has a similar composition, calcium being the most abundant compound, followed by Si, Al, Cl, Fe, and lower concentrations of K, Mg and Na. In all cases, lower gasification temperatures lead to lower concentrations of inorganic elements retained in the dust captured in the filter.

To sum up this section, it has been shown that gasification temperature shifts the distribution of the elements retained in each product fraction. In particular, lower temperatures lead to a decrease of the chlorine released to the gas phase, an increase of retention in the cyclone ash and a decrease in the fraction retained in the filter dust.

3.3 Deposition probe analysis

In order to make a consistent study of the fouling tendency of the fuels tested, a deposition probe was designed and implemented during the lab-scale experiments. The probe consists of two concentric steel pipes through which cooling water flows. Water at ambient temperature (~ 100 L/h) enters though the inner pipe and after reaching the bottom, circulates through the outer pipe. At the bottom there is a stainless steel probe (20 mm x 20 mm x 6 mm) attached, with an internal thermocouple for temperature control. The whole piece is surrounded by ceramic insulating material and is flanged at the top of the gasifier, so that the probe is located below the outlet pipe of the producer gas (i.e. all the gas flows along the probe). The probe temperature, kept around 250-350°C during the tests in order to simulate the fouling behavior on the gas cooler surface, is online monitored and logged during the tests.

The probe was weighed before and after the tests, a visual inspection was carried out, and was stored for further SEM/EDX analysis. Figure 11, Figure 12 and Figure 13 display some examples of the SEM/EDX analyses performed on the deposits of the collected probes, including examples of composition of selected spectra.

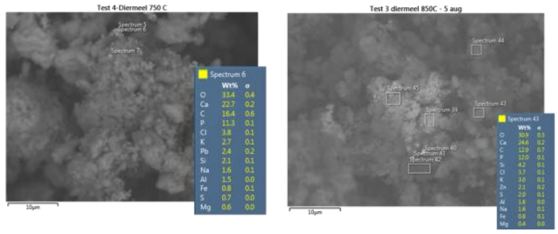


Figure 11: SEM/EDX analysis of deposits from MBM gasification: 750°C (left), 850°C (right).

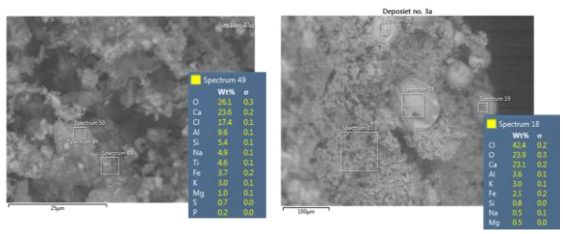


Figure 12: SEM/EDX analysis of deposits from paper rejects gasification: 750°C (left), 850°C (right).

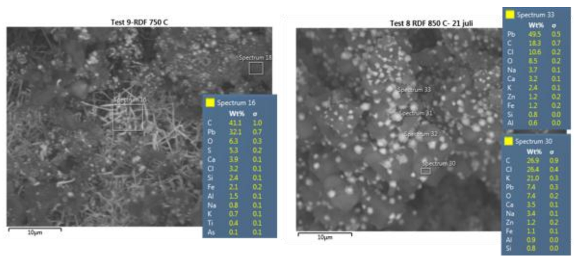


Figure 13: SEM/EDX analysis of deposits from RDF gasification: 750°C (left), 850°C (right).

The SEM/EDX measurements have revealed that deposits produced during gasification of paper rejects (Figure 12) contain a significant amount of salts like $CaCl_2$, NaCl, KCl, or $AlCl_3$. Deposits from RDF gasification (Figure 13) are similar to those of paper rejects, but it is noteworthy remarking their larger content of $PbCl_2$. On the contrary, deposits produced from MBM are rich in Ca and P, but contain less chlorine and therefore less salts in deposits. In general, it has been found that gasification at high temperature (850°C) results in more dense, partially molten and sintered deposits, with significantly higher concentration of chlorine. On the contrary, lower gasification temperatures result in more porous and fluffy deposits.

4 PAPER REJECTS GASIFICATION IN 25 KW_{th} MILENA GASIFIER

Low-temperature gasification of paper rejects was tested in the lab-scale MILENA. The gasification temperature (approximately 730°C) was selected on the basis of the conclusions obtained in the 5 kW_{th} BFB tests (see Section 3).

Unlikely direct gasification, two different gaseous streams are generated in indirect gasification: producer gas and flue gas. Each of these gases contain dust with a different composition. Figure 14 displays the gas phase composition of producer gas and flue gas generated in MILENA gasification. As can be observed, the most significant contribution to the producer gas phase is Cl (~1.7 g/Nm^3 dry gas, which is equivalent to 1098 ppmv dry), followed by NH_4^+ (0.3 g/Nm^3 dry, i.e. 386 ppmv dry), and traces of S, Si, Sn and Pb (< 0.025 g/Nm^3 dry). The concentration of the rest of elements is below detection limits. When comparing with results from direct BFB gasification of paper rejects at low temperatures (Figure 7 (b)), it can be checked that the gas-phase concentration of Cl and NH_4^+ in producer gas from MILENA indirect gasification is about the same order as that from direct gasification despite the different residence time of the gasifiers. On the other hand, the only significant contribution to the MILENA flue gas phase is Cl (~0.5 g/Nm^3 dry or ~341 ppmv dry).

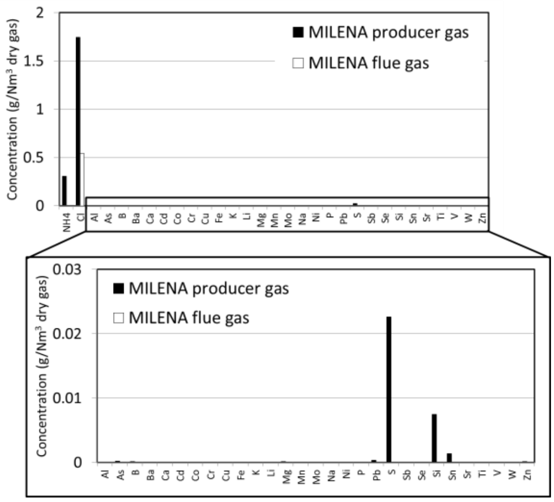


Figure 14: Composition of producer gas phase and flue gas phase from MILENA gasification.

Figure 15 plots the composition of the dust contained in the producer gas and the flue gas streams. It can be seen that the dust entrained in the producer gas is mainly composed of Ca, Cl, Si, Mg, Al, and Fe. On the contrary, the dust collected in the cyclone of the flue gas side is mainly composed of Mg and Si, with small amounts of Al, Fe, Ca and Cl. When comparing with results of direct BFB gasification at low temperature (Figure 9), it can be checked that, despite a similar distribution of elements, MILENA gasification produces roughly twice as much dust fly ash than direct BFB gasification. This might be due to the higher gas velocity in the MILENA riser, which favors the entrainment of particles in the gas.

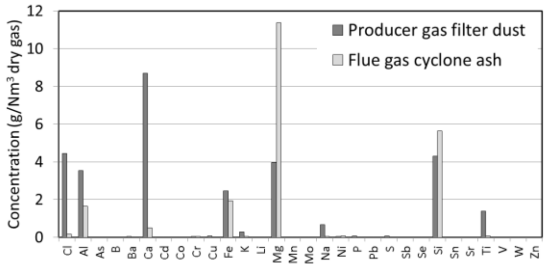


Figure 15: Composition of producer gas dust and flue gas cyclone ash generated in MILENA indirect gasification.

5 LARGE-SCALE (80 MW_{th}) RDF/WOOD CO-GASIFICATION TESTS

The effect of replacing wood with a fraction of low-value feedstock (RDF) has been assessed at the 80 MW_{th} CFB gasifier located at the Amer 9 power plant. In preliminary co-gasification tests with 20% wt. RDF and 80% wt. demolition wood at 840°C, it was found that fast fouling of the gas cooler took place. The fouling appeared to be caused by $CaCl_2$. After that, it was suggested that the gasifier temperature should be reduced in order to decrease the fouling rate of the gas cooler. After several adjustments in the gasifier operation (fuel/air ratio, removal rate of bed material), the gasification temperature was progressively decreased. The temperature range between 770-800°C was found to be a critical margin for the vaporization and condensation of salts. During January-March 2014 a long-duration co-gasification test was carried out in the CFB gasifier at ~750°C using RDF/wood mixtures as feedstock. During the test, the fraction of RDF fed to the gasifier was increased from 0% to 25% and finally 40% wt. A total of 5685 ton fuel (3717 ton demolition wood + 1968 ton RDF) was gasified during 302 hours, with reduced gas cooler fouling appreciated. An overview of the test can be seen in Figure 16.

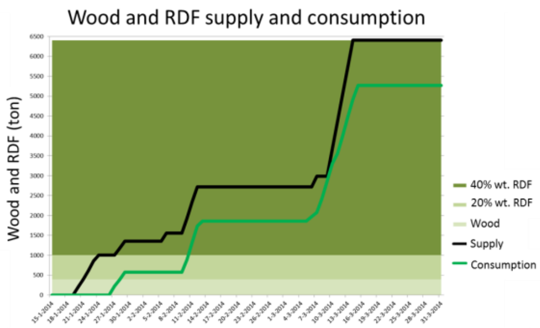


Figure 16: Wood and RDF supply and consumption in the 80 MW_{th} CFB gasifier co-gasification test.

During the test it was found that, with respect to 100% wood gasification, RDF/wood co-gasification leads to an increase by 50% in the bottom ash production due to the higher ash content of RDF. This implies that the removal rate of bottom ash had to be increased, and this is the limiting factor of the maximum feasible amount of

RDF than can be fed to the gasifier. Thus, the bottom ash removal system will probably have to be adapted if higher fractions of RDF are to be used. Even though the higher build-up of ash from the fuel would lead to decrease of the required make-up sand supply, issues like different fluidization behavior or accumulation of certain ash compounds in the bed might occur. The amount of fly ash is also higher when replacing part of the wood with RDF. The removal efficiency of the double cyclone system was found to be lower during RDF/wood co-gasification than in pure wood gasification.

With respect to producer gas composition, 40% wt. RDF/wood co-gasification leads to the production of a gas with a heating value of 5.6 MJ/Nm^3 dry, i.e. 10% higher than producer gas from pure wood gasification. The normalized concentration of heavy metals in the producer gas, (As+Co+Cr+Cu+Mn+Ni+Pb+Sb+V)/fuel heating value, was found to be 19.3 mg/MJ, that is, below emission limits (30 mg/GJ).

Therefore the large-scale tests have shown that the gas cooler fouling, the main concern issue in the plant, can be limited by decreasing the gasification temperature, thus increasing plant availability, in consistency with the results obtained in the laboratory. By applying this measure, up to 15-20% wt. RDF can be co-gasified without remarkable operating problems. However, higher fractions of RDF in the fuel cause a fast fouling even at lower temperatures, mainly due to the fly-ash content in the producer gas. Therefore, additional modification of the gas cooler will be necessary.

6 CONCLUSIONS

With the aim of the adaptation and optimization of the gasifier + boiler technology for the efficient conversion of low-value feedstock in order to reduce the production costs of renewable electricity, experimental tests have been carried out both at lab-scale (5 kW_{th} BFB, 25 kW_{th} MILENA gasification) and commercial-scale (80 MW_{th}) using different troublesome, low-value feedstock.

In the 5 kW_{th} BFB tests it has been found that a decrease in gasification temperature from 850°C to 750°C leads to a trade-off between fuel conversion and release of contaminants to the gas phase. Furthermore, a different quantitative distribution of fouling elements in the solid- and gas phase has been observed. Even though lower temperatures lead to a higher production of tars (i.e. lower fuel conversion to producer gas), the tars produced contain a lower fraction of heavy tars, and most importantly, the concentration of HCl in the gas phase is decreased. Moreover, at lower temperatures, there is an increase of the elements retained in the cyclone ash, and a lower concentration of elements retained in the filter dust. Producer gas from MBM gasification contains the highest concentration of NH_3 (2.5-3.3% vol. dry), whereas paper rejects gasification produces the highest amount of HCl in the gas (~1700 ppmv dry). The large moisture content of paper rejects might be responsible for the dramatically higher HCl content in the producer gas with respect to the (similar in composition) RDF. The SEM/EDX analyses performed to the produced deposits have revealed that high-temperature gasification results in more dense, partially molten and sintered deposits with higher Cl concentration (thus, prone to fouling and corrosion), whereas low-temperature gasification results in more porous and fluffy deposits. Paper rejects gasification produces deposits with a significant amount of salts like $CaCl_2$, NaCl, KCl, or $AlCl_3$. Deposits from RDF gasification are similar to those of paper rejects, but contain a larger amount of $PbCl_2$. Deposits from MBM gasification are rich in Ca and P, but contain less chlorine and therefore less salts.

Low-temperature paper rejects gasification carried out at the 25 kW_{th} MILENA has shown that the gas-phase concentration of Cl and NH_4^+ in the producer gas from MILENA gasification is similar to that from direct gasification despite the different residence time of the gasifiers.

Lastly, results of wood/RDF co-gasification at the 80 MW_{th} CFB gasifier of the Amercentrale 9 plant have shown that the gas cooler fouling, the main concern issue in the plant caused by the replacement of wood by RDF, can be reduced by decreasing the gasification temperature, in consistency with the results obtained in the laboratory. By applying this measure, up to 15-20% wt. RDF can be co-gasified without remarkable operating problems. Therefore, lower gasification temperatures lead to higher plant availability. However, higher fractions of RDF in the fuel cause a fast fouling even at lower temperatures, mainly due to the fly-ash content in the producer gas. Additional modification of the gas cooler and the bottom-ash removal system will be necessary if higher fractions of RDF are to be fed to the gasifier.

7 REFERENCES

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8 ACKNOWLEDGEMENT

The Dutch Ministry of Economic Affairs is gratefully acknowledged for its support through the TKI Project “Vergassen laagwaardige brandstoffen” (reference TEBE213002). The authors are also indebted to M. Geusebroek, P. Heere, D. Slort and A. Toonen for their invaluable assistance during the experiments.

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