

# Steam gasification of waste tyre: influence of process temperature on yield and product composition

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## Riassunto

*La produzione mondiale di pneumatici usati ammonta a 7 milioni di tonnellate, di cui 3 milioni nella sola Comunità Europea. Per questo tipo di rifiuti la messa in sicurezza in discarica rappresenta ancora la via di smaltimento più adoperata in molti Paesi.. Per affrontare una corretta gestione di queste enormi quantità di rifiuti, sono state considerate molte alternative; tra queste, le tecnologie di trattamento termico sembrano rappresentare una via incoraggiante per il recupero sia di energia sia di materia. In particolare, la pirolisi e la gassificazione sono applicazioni interessanti in virtù dell'ottenimento di sottoprodotti ad alto valore aggiunto. Il lavoro in oggetto riguarda le prove sperimentali e i risultati ottenuti nella gassificazione con vapore di pneumatici di rifiuto, allo scopo di valutare l'influenza della temperatura sulla resa e sulla composizione dei prodotti.*

## Summary

*The world production of tyre waste amounts to 7 millions of tons, 3 millions of which are generated in Europe. For this waste stream the landfill is the most practiced way of disposal in many Countries. In order to perform a correct management of this huge quantity of waste, many options were considered. Among these, thermal technologies seem to be an encouraging way to attain energy and/or matter recovery.*

*Pyrolysis and Gasification are very interesting application to produce high added value by-products. Present work relates to experimental tests and obtained results of Scrap Tyre gasification with steam, with the aim of evaluating the influence of the process temperature on the products yields and compositions.*

## 1. Introduction

The world production of tyre waste amounts to 7 millions of tons (ref. ETRA, 2008), 3 millions of which are generated in Europe, that is 2% of total solid waste production, and even today the final destination of nearly 65-70% of such an amount is the landfill, with the consequent loss of high added value materials [1] and the relevant environmental impact.

It is well known that scrap tyres possess high volatile and low ash content with heating value greater than coal and biomass. These properties make it an ideal material for thermal processes like pyrolysis and gasification, that, unlike combustion, convert the intrinsic chemical energy of a carbon-rich material in valuable by-products. Among these thermal technologies, gasification of scrap tyres seems to be an attractive method since the gaseous fuel derived from the process can be stored, transported and easily fuelled for existing boilers and combustors with little modifications, but at moment the experiences are limited to bench or pilot scale studies [2-4]. Another alternative consists in conveying the syngas in a fuel cell, which allows one to improve the overall efficiency of the process. In a modern fuel cell, such as a molten carbonate cell, a steady stream of hydrogen is required as fuel: this means that syngas usage for those

applications normally requires a suitable cleaning from trace contaminants and the appropriate upgrading of the composition [5].

Within this framework, the present study reports results of scrap tyre gasification with steam, according to a series of trials performed using a bench-scale reactor, with the final goal of determining the influence of processing temperature on yields and product composition.

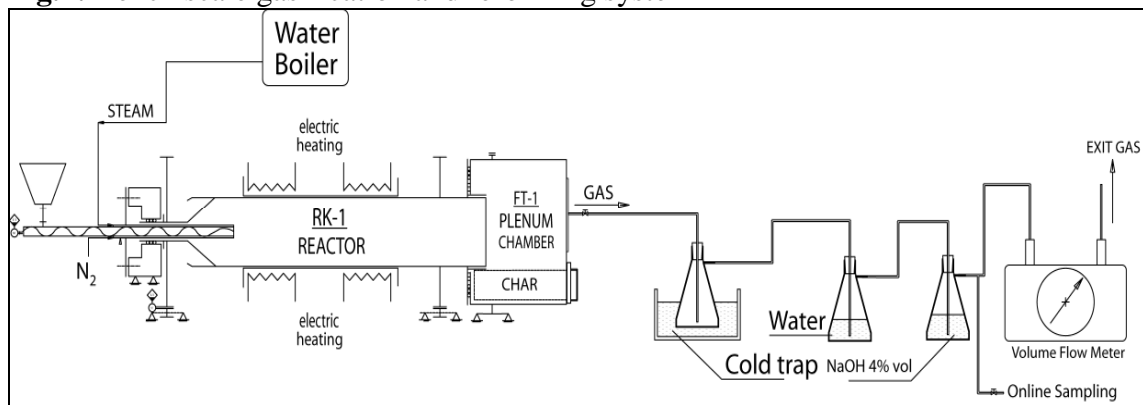
## 2. Results and discussion

### 2.1 Materials and apparatus

Samples used for the experimental work are commercial products, supplied by an Italian producer (Elastrade). Tyre samples were milled till to a size of maximum 6 mm and kept at ambient conditions.

The gasification tests have been carried out on a continuous bench scale plant, built and tested at ENEA in-house facilities (see Fig.1).

**Fig.1:** Bench scale gasification and reforming system



The material was loaded into a feeder hopper and continuously fed into the reactor. After the treatment, the solid residue was continuously discharged in a tank at the outlet of the reactor while the process gas was headed for the cleaning system and, afterwards measured before being analyzed and discharged in the vent system.

The steam for the gasification tests was produced in a boiler and pumped into the reactor through a peristaltic pump at a fixed rate.

On-line gas analyses were conducted using a process gas chromatograph Agilent model 3000A equipped with two parallel columns (Molsieve 5A and Poraplot Q), and a TCD. Argon was used as carrier gas.

Ultimate analyses were obtained with a ThermoQuest EA 1110 analyser. A TA Instruments model TGA 2950 system was used to set up the thermal process and characterize the tyre samples, with respect to proximate analysis (that is, moisture, volatile matter, fixed carbon, and ash content of the material); the ash content was further evaluated by incineration at 1000 °C.

### 2.2 Characterization of scrap tyres and gasification tests

Table 1 reports the proximate and ultimate analysis of scrap tyres. Data show that the starting material, on a dry base, is shared for more than 65% into the volatile fraction and for 26% into the solid residue, together with the ash (6.8%). Ultimate analysis shows a high carbon content and a significant sulfur amount, up to 2%.

**Tab.1:** Proximate and ultimate analysis of starting material

	weight* (wt %)		weight* (wt %)
<b>C</b>	77.3	<b>Volatile</b>	67.7
<b>H</b>	6.2	<b>Fixed C</b>	25.5
<b>N</b>	0.6	<b>Ash</b>	6.8
<b>S</b>	1.8		
<b>O</b>	7.1 (by difference)		
<b>Density</b>	0.8 g/dm <sup>3</sup>		

\*on dry basis

The steam gasification of tyres were performed in a series of trials at different processing temperatures, in the range of 850-1000 °C, holding all other operational parameters constant (rotational speed of reactor, feeding rate, carrier gas flux), as reported in Table 2; such parameters, in turn, fix the solid and gas residence times.

**Tab.2:** Operational and process parameters

test	Temp. (°C)	Pressure (bar)	Carrier gas flow (N <sub>2</sub> ) (l/min)	Steam/tyre ratio	Solid residence time (min)	Gas residence time (s)
T1SGTy	850	1	1.0	2	>100	6.2
T2SGTy	925	1	1.0	2	>100	5.7
T3SGTy	1000	1	1.0	2	>100	5.3

The influence of temperature on the process variables has been studied through comparison of the different trials, with respect to the yields, to the chemical composition and to the mass balances of the main components of the process.

Table 3 reports the yields of the various process fractions (char, oil, and gas) at different temperatures: the data show that the mass balance exceeds 100%, because of the introduction of steam; it is important to remark that the oil fraction was determined by weight difference of the cold trap. Furthermore, as expected, at higher temperature, the char yield progressively decreases while the gas yield increases.

**Tab.3:** Fractional yield

test	char yield (wt%)	oil* yield (wt%)	gas yield (wt%)
T1SGTy	43.4	27.0	34.7
T2SGTy	38.5	21.8	64.5
T3SGTy	33.3	5.3	85.9

\*oil = condensable fraction of tar and soot

In regard to the gas fraction, the principal components (apart from nitrogen, which was used as the carrier gas) detected over the different trials and reported in Table 4 were H<sub>2</sub>, CH<sub>4</sub>, CO, CO<sub>2</sub>, and small quantities of some hydrocarbons, such as ethane, ethylene, and acetylene.

**Tab.4:** Gas composition versus process temperature

test	H <sub>2</sub>	CO	CO <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>2</sub>	C <sub>2</sub> H <sub>6</sub>
	% vol	% vol	% vol	% vol	% vol	% vol	% vol
T1SGTy	52.8	5.9	3.9	26.6	9.3	0.8	0.7
T2SGTy	56.5	15.9	4.9	17.2	4.5	0.8	0.1
T3SGTy	65.2	17.4	7.8	8.7	0.6	0	0.3

Higher temperatures clearly result in higher hydrogen concentrations; the hydrogen content rapidly increases, attaining values of >65%, while the hydrocarbons, particularly methane and ethylene, gradually decrease; (other than carbon monoxide and dioxide, whose concentration clearly depends on the contemporary effects of Boudouard and water gas shift reaction) over the range of the temperatures. This situation is probably dependent on the more favorable thermal cracking and steam reforming reactions that were caused by higher temperatures, which result in the major extensions of secondary cracking reactions into the gas fraction [6-7].

**Tab.5:** Gas characterization

parameter	value		
	T1SGTy	T2SGTy	T3SGTy
C (wt %)	60.2	48.9	38.1
H (wt %)	22.5	16.8	15.1
O (wt %)	17.4	34.3	48.9
Gas heating value			
GHV (MJ/m <sup>3</sup> gas)	25.1	19.1	14.6
GHV (MJ/kg of feed)	16.7	22.0	25.0
Gas density at n.c. (kg/m <sup>3</sup> )	0.5	0.6	0.5

Table 5 reports the elemental composition (carbon, hydrogen and oxygen) of the synthesis gas, which shows that, as the temperature increases, the carbon content continuously decreases, while the oxygen content increases; the hydrogen, being the main component of the gas fraction and having a small atomic weight, is responsible for the progressive reduction of the gas density at higher temperature.

As reported in Table 6, the higher temperatures, together with the presence of the steam, strongly influence the total volume of the gas produced, and with an increase in temperature from 850 °C to 1000 °C, the gas volume per kilogram of feeding definitely triples. This aspect becomes more significant if each contribution of the components of the gas mixture is taken into account; as it would be expected, hydrogen mainly affects the gas production at higher temperature, reaching a value of 1.12 m<sup>3</sup>/kg at 1000 °C,

over a total production of 1.70 m<sup>3</sup>/kg. The progressive increase of hydrogen and carbon monoxide production is a clear indication of the major extension of secondary cracking reactions [8-10]; moreover, the methane behavior, that is gradual decrease at higher temperature, is a compromise between the improved global gas production and the contemporary extended secondary cracking mechanisms.

**Tab.6:** Gas composition at different temperature

test	H <sub>2</sub> m <sup>3</sup> /kg	CO m <sup>3</sup> /kg	CO <sub>2</sub> m <sup>3</sup> /kg	CH <sub>4</sub> m <sup>3</sup> /kg	C <sub>2</sub> H <sub>4</sub> m <sup>3</sup> /kg	C <sub>2</sub> H <sub>2</sub> m <sup>3</sup> /kg	C <sub>2</sub> H <sub>6</sub> m <sup>3</sup> /kg	total m <sup>3</sup> /kg
T1SGTy	0.34	0.04	0.02	0.20	0.06	0.00	0.00	0.70
T2SGTy	0.64	0.22	0.05	0.18	0.05	0.01	0.00	1.20
T3SGTy	1.12	0.30	0.13	0.15	0.01	0.00	0.01	1.70

### 3. Conclusions

As a first conclusion, steam gasification of scrap tyres seems to be a promising process in view of obtaining a good quality syngas.

The data show that a higher temperature results in a higher syngas production. Furthermore, when all the operational parameters are held constant, the temperature definitely affects gas composition, in favour of a higher hydrogen production at higher temperature; with respect to the calorific value, the syngas seems to be comparable to natural gas.

The adopted operating conditions allow to obtain an appreciable amount of char, whose high carbon content suggest its exploitation both as activated carbon (after activation process) and as carbon source for synthesis reactions.

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### 4. References

1. E.L.K. Mui, D.C.K. Ko, G. McKay, Carbon, 42 (2004) 2789
2. S. Galvagno, S. Casu, T. Casabianca, A. Calabrese, G. Cornacchia, Waste Manag., 22 (2002) 917
3. D.Y.C. Leung, X.L. Yin, Z.L.Zhao, B.Y. Xu, Y. Chen, Fuel Process. Technol., 79 (2002) 141
4. A.A. Zabaniotou, G. Stavropoulos, J. Anal. Appl. Pyrol., 70 (2003) 711
5. W. Wu, K. Kawamoto, H. Kuramochi, J Mater Cycles Waste Manag 8 (2006) 70
6. S. Turn, C. Kinoshita, Z. Zhang, D. Ishimura, J. Zhou, Int. J. Hydrogen Energy, 23(8) (1998) 641
7. S., Lin, M. Harada, Y. Suzuki, H. Datano, Fuel 83 (2004) 869
8. P. Morf, P. Hasler, T. Nussbaumer, Fuel 81 (2002) 843
9. M.L. Boroson, J.B. Howard, J. P. Longwell, W.A. Peters, Energy Fuels 3 (1989) 735
10. J.M. Encinar, J. F. Gonzalez, J. Gonzalez, J. Fuel Process. Technol. 75 (2002) 27