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LOW-TEMPERATURE PROCESSING OF WASTE TYRES IN EXPERIMENTAL RETORT

R. JOONAS, V. YEFIMOV, S. DOILOV
Institute of Oil Shale at Tallinn Technical University
12 Järveküla St., Kohtla-Järve, 30328 Estonia

G. SERKOVSKAJA
Scientific-Research Centre of Carcinogenesis,
Oncological Centre of the Russian Academy of Medical Sciences
24 Kashirskoje Rd., 115478 Moscow, Russia

Testing of waste tyre chips (60–80 mm) in an experimental retort at the end of 1998 was successful. Descending of tyre particles along the retort occurred normally when practically dry coke was discharged. No soot formation was observed. Throughput rate of the retort was 660 kg tyres daily, oil yield – 46 % (83 % of the Fischer Assay yield). The coke formed was reduced to small pieces, mostly down to 6.3 mm.

The coke formed has chemical and physical properties enabling to create a nonwaste technology for retorting waste tyres. Successful processing of tyre chips in the experimental retort should be followed by testing on industrial scale.

Introduction

Gradual exhaustion of natural resources and the rise in their prices as well as the environmental problems raise a question of utilizing waste tyres as one of the most urgent tasks of the present day. It follows that this important task is to be solved from both economical and environmental points of view. Wastes of rubber industry represent a most important kind of secondary resources.

The problem of waste tyre utilization is a live issue in all industrially developed states of the world, and intensive research and development work in this field is being carried out [1].

Technical solutions for utilization of worn-out tyres are to be found in Estonia and in other Baltic states, too, since there is no way for their further utilization and they are thrown out in the vicinity of residential areas and factories thus polluting the environment. In Estonia, 15,000 t of waste tyres are thrown out every year. This number cannot be less in Latvia and Lithuania. The long-time experience of kukersite oil shale thermal processing in Estonia offers a good possibility to test this method on waste tyres. Such a solution to the waste tyre problem is of a great practical interest.

Laboratory tests made at the Institute of Oil Shale at Tallinn Technical University demonstrated that retorting of waste tyres yielded up to 50 % low-sulfur oil. Semicoke formed had a very high heating value – 25–29 MJ/kg (6000–7000 kcal/kg). It means that waste tyres used as raw material may be processed waste-free since semicoke obtained may be utilized as high-calorific solid fuel [2]. Utilization of secondary raw material also improves the economical balance of a state. Consequently, total utilization of waste tyres not only solves the environmental problem but also creates a new source of power-generating fuel.

Continuously rising prices of oil shale will finally lead to the inexpediency of producing its liquid products as shale oil will not be able to compete with petroleum products on the oil market. This compels us to look for a new alternative raw material for Estonian oil shale industry enterprises. Waste tyres may turn out to be an acceptable solution.

The main problem is how the rubber particles will behave under their thermal processing conditions in vertical retorts: whether it will be possible to avoid hanging of rubber particles and abundant soot formation, and whether the tyres may be processed alone or mixed with oil shale only. It is most important to find a technological solution for cutting waste tyres into 60–80 mm pieces as well.

To solve the problem, we chose to carry out the experiments with tyre chips at the experimental retort developed at the Institute of Oil Shale and constructed in 1995 by *Viru Õlitööstus* AS. Its throughput rate is 600–700 kg of shale per day [3]. The construction of this retort was financially supported by the Commission of the European Communities (the programme JOULE-PECO, contract No ERB CIPD 930-357).

The testing was carried out by the co-workers of the institute and by the staff of the unit GGS-4 of the *Viru Õlitööstus* AS. The latter placed an order for cutting of 4 t waste tyres into 60–80 mm pieces with a local firm at Kohtla-Järve (scientific-technical enterprise *Gemma NT*). The order was filled excellently – the metal cord of tyres remained within the particles.

By the way, rubber waste transported from Europe is being processed at a unit with solid heat carrier SHC-3000 operating in Narva at Estonian Power Plant. However, at this unit fine-grained material is processed in the flow of solid heat carrier. Rubber waste is mixed with oil shale in the ratio 1 : 9 or 2 : 8 [4]. The oil formed is a mixture, too, and consists of shale oil and oil of rubber origin. As waste tyres contain metal cord, they cannot be processed at SHC-3000.

Table 1. **Characteristics of the Retorting Waste Tyres**

Indices	Value
Bulk weight, kg/m^3	430
Moisture of waste tyres tested in experimental retort, %	0.9
Content (dry basis), %:	
Carbon dioxide $(CO_2)^d{}_M$	0.1
Ash A^d	9.3
Organic matter $100 - (CO_2)^d{}_M - A^d$	90.6
Total sulphur $S^d{}_t$	1.15
Volatile matter (dry basis), %	63.0
Fischer Assay product yield (standard retort), %:	
Oil	55.6
Pyrogenic water	1.8
Semicoke	35.8
Gas and losses (by difference)	6.8
Fischer Assay oil of organic matter, %	61.4
Specific gas yield,* m^3/t	36.0
Calculated gas heating value,* MJ/m^3 (kcal/m^3):	
Gross	59.91 (14310)
Net	55.81 (13330)
Heating value (bomb calorimeter),	
MJ/kg	36.38
kcal/kg	8690

*Here and later on all characteristics of gas are given at 20 °C and 760 mm Hg.

Results

Characteristics of waste tyres are given in Table 1. Tyres contain 90.6 % organic matter; Fischer Assay oil yield reached 55.6 %. Their heating value was 36.38 MJ/kg (8690 kcal/kg). In the retort burner the product gas from the unit GGS-5 was used. Its composition was fairly stable guaranteeing its even combustion in the burner.

During the first trial (13.–14.10.1998) the coke was discharged through an extractor filled with water. It was let out at the end of the experiment testing when discharge of coke had stopped as fine coke floated on the water surface and did not discharge. This led to an immediate renewal of the normal coke discharge. Some water was left on the extractor bottom. In order to avoid overheating of extractor elements, steam was introduced.

In the case of the second trial (26.–28.10.1998) the throughput rate of the was 656 kg/day instead of 1087 during the first trial. At the rate 1087 kg/day the oil yield had been 35.9 %, and some unretorted rubber particles were discharged from the extractor. At the lower rate the oil yield increased to 45.9 %, and all rubber was processed. The first throughput rate was probably too high to attain the optimum oil yield. The operating conditions of retorting waste tyre particles are given in Table 2.

Table 2. **Operating Conditions of Waste Tyres Pyrolysis Process in the Experimental Retort**

Indices	Test 1	Test 2
Feed of waste tyres pyrolysis process, kg/day	1087	656
Temperatures, °C:		
Oil vapours from the retorting zone	232	301
Heat carrier into retorting zone	635	686
Heat carrier preparation and distribution chamber	673	744
FInal temperature at the end of condensation system	–	40
Underpressure at gas outlets, Pa (mm water column)	441 (45)	196 (20)
Product yields from initial waste tyres, kg/t:		
Oil	359	459
Coke	350	340
Retort water	50	57

Table 3. **Properties of Oil Obtained in the Experimental Retort from Waste Tyres**

Indices	Value
Yield of oil, %:	
Plant yield:	
raw tyre basis	45.9
dry tyre basis	46.3
Yield of Fischer Assay oil, %	83.2
Density at 20 °C, g/cm^3	0.953
Water, %	8.5
Viscosity at 80 °C, 10^{-6} m^2/s	8.6
Entrained fines, %	0.24
Ash, %	0.01
Flash point, °C	97
Pour point, °C	+12
Coking value (Conradson carbon residue), %	7
Phenolic compounds, %	No
Heating value (bomb calorimeter), MJ/kg (kcal/kg)	43.04 (10280)
Initial boiling point, °C	180
Distillation, vol.%, at:	
200 °C	3
220	4
240	10
260	14
280	18
300	24
320	32
340	42
360	64
Elemental composition (dry basis), %:	
C	87.9
H	10.5
S	1.1
O + N (by difference)	0.5

During the second trial the oxygen content of the gaseous heat carrier was determined. This number was 1.7 % indicating that the utilization of the air in the burner had been quite satisfactory. This is probably the reason why no intensive soot formation took place (also confirmed by a low – only 0.24 % – content of mechanical admixtures in rubber oil).

During the second trial (28.10.98) the gasoline content of retorting gas was determined using adsorption on active carbon. 300 l of gas was passed through, and the result obtained was extremely low – 4.6 g/m^3.

The characteristics of the oil obtained at the second trial are presented in Table 3, these of the coke – in Table 4. The coke has a very high heating value (24.83 MJ/kg or 5930 kcal/kg) – a good basis for creating a nonwaste technology of waste tyre pyrolysis. As seen from Table 4, the material greatly breaks up in the retort.

Table 4. **Properties of Coke Obtained in the Experimental Retort from Waste Tyres**

Indices	Value
Yield of dry coke, kg/t	340
Moisture content, %	40
Content (dry basis), %:	
Carbon dioxide $(CO_2)^d{}_M$	1.8
Ash A^d	27.7
Organic matter $100 - (CO_2)^d{}_M - A^d$	70.5
Total sulphur $S^d{}_t$	2.4
Volatile matter (dry basis), %	4.8
Fischer Assay oil yield from coke, %	0.25
Heating value (bomb calorimeter), MJ/kg (kcal/kg)	24.83 (5930)
Granulometric composition of the coke, %:	
<0.2 mm	15.72
0.2–1.25	40.99
1.25–6.3	35.52
>6.3	7.77
Content of waste steel, %	24

The gas formed is low-calorific – 1.45–1.65 MJ/m^3 (350–400 kcal/m^3) due to the very high special consumption of the air (600–800 m^3/t) caused by big thermal losses into surroundings, especially from the side combustion chamber. Combustion heat of the gas would be 3–4 times higher when produced on the industrial scale.

The yield of tar water was 50–57 l/t (Table 2), its pH – 4.0–5.5. The balance of chemical heat at processing of waste tyres in the experimental retort is given in Table 5, the material balance of this process – in Table 6.

Table 5. **Heat Balance in testing of Waste Tyres in the Experimental Retort**

Indices	MJ/kg	kcal/kg	%
FEED			
Waste tyres ($W^r \approx 1.0$ %)	36.00	8600	89.5
GGS-5 product gas 1.154 m^3/kg· 2.51 MJ/kg	2.90	692	7.2
Gasoline in the GGS-5 product gas 1.154 m^3/kg· 0.025 kg/m^3· 46.05 MJ/kg	1.33	317	3.3
Total	40.23	9609	100.0
PRODUCTS			
Oil* 0.459 kg/kg· 43.04 MJ/kg	19.75	4718	49.1
Retorting Gas* 1.332 m^3/kg· 1.55 MJ/kg	2.06	493	5.1
Gasoline in the Retorting Gas* 1.332 m^3/kg· 0.046 kg/m^3· 43.54 MJ/kg	0.27	64	0.7
Coke (excl. steel scrap)* 0.340 kg/kg· 24.83 MJ/kg	8.44	2016	21.0
Heat for the process and heat losses, inaccuracy of analysis (by difference)	9.71	2318	24.1
Total	40.23	9609	100.0
*Total Chemical Heat in useful products	30.52	7291	75.9

Table 6. **Material Balance in Testing of Waste Tyres in the Experimental Retort**

Indices	kg	%
FEED		
Waste tyres	1.000	39.18
GGS-5 product gas 1.154 m^3/kg· 1.32 kg/m^3	1.523	59.68
Gasoline in the GGS-5 product gas 1.154 m^3/kg· 0.025 kg/m^3	0.029	1.14
Total	2.552	100.0
PRODUCTS		
Oil	0.459	17.99
Retorting gas 1.332 m^3/kg· 1.23 kg/m^3	1.638	64.18
Gasoline 1.332 m^3/kg· 0.046 kg/m^3	0.006	0.23
Coke (incl. steel scrap)	0.447	17.52
Balance error and inaccuracy of analysis (by difference)	0.002	0.08
Total	2.552	100.0

Conclusion

The experiments made with waste tyre particles (60–80 mm) in the experimental retort were successful. The tyre chips descended normally in the retort at practically dry discharge of the coke from the extractor. No soot formation was observed evidenced by a low content of mechanical admixtures in the tyre oil – 0.24 %.

Throughput rate of the retort was about 660 kg waste tyres per day. The oil yield was 46 % (83 % of the Fischer Assay oil yield). The oil formed was paraffinic in nature the pour point being +12 °C. The bomb-calorimetric value of this oil was 43 MJ/kg (10280 kcal/kg), sulfur content – 1.0–1.1 %. The content of light fractions boiling below 200 °C was 2–3 vol.%, that of benzo(a)pyrene – 28 mg/kg (50–80 mg/kg in the kukersite shale oil).

The coke yield (without steel scrap) was 340 kg/t. Coke contained 24 % waste steel. The total coke yield (together with metal cord) was 447 kg/t. Coke had the following granulometric composition (wt.%):

<0.2 mm – 15.72
0.2–1.25 mm – 40.99
1.25–6.3 mm – 35.52
>6.3 mm – 7.77.

Coke had a very high heating value (measured in bomb calorimeter) – about 24 MJ/kg (5700 kcal/kg). It contained 4.8–5.7 % volatile compounds (63.0 % in the initial material), and 2.4–2.7 % total sulfur. Benzo(a)pyrene content was 1.3 μg/kg – an amount that does not exceed the natural background. Its content in oil shale semicoke is 20–80 μg/kg.

The coke formed from waste tyres has good physical and chemical properties meaning that waste tyres may be retorted practically waste-free.

The tar water (pH – 4.0–5.5) was formed in an amount of 50–57 l per ton of waste tyres.

Good results obtained at test processing of waste tyres in the experimental retort will serve as a basis for testing the tyres under industrial conditions. The retort to be used must be reconstructed in a way that enables dry discharge of tyre coke.

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