Experience with using alternative reducing agents at blast furnace*

J. Buchwalder, T. Fuchs, J. Hunger, T. Siepert
(EKO Stahl)

This paper presents the experience that EKO Stahl has gained with the blast furnace injection of plastics and animal fats as alternative reducing agents since 1993. The specific pieces of equipment that have been designed and implemented for handling, storing and injecting these substances into the blast furnace tuyeres are described.

The parameters that allow line stability and the overall effects on blast furnace operation are reported.

■ INTRODUCTION

Presently operated blast furnaces 5 and 1 of EKO Stahl, are equipped for injecting heavy fuel oil while BF 1 is also equipped for injecting fine-grained or granulated solid matters.

In the normal operation mode, BF 5 is fed with 100 % heavy fuel oil. The objective is to operate BF 1 with 100 % mixed plastics agglomerate, as it had been achieved with BF 3 until may 2001.

■ HISTORICAL DEVELOPMENT OF ALTERNATIVE REDUCING AGENTS INJECTION AT EKO STAHL

Already in 1993, large-scale industrial tests started on blast furnace 6 with the injection of plastics in granulated form, that were continued with other injection materials until 1995, e.g. light shredder fraction, oily mill scale, sedimentation and varnish mud granulate.

In 1993 and 1994, tests were performed using the above-mentioned materials. Injection quantities and times have been correspondingly short (1).

Diagrams (*fig. 1, 2*) for carbofer (mix of oily mill scale and flue ash) and light shredder fraction show increased injection rates and injected quantities of different substances (2, 3).

In 1995 and 1996 during a test period of 12 days, technologically interesting quantities of the light shredder fraction and the mix of oily mill scale and flue ash could be injected into the blast furnace through the tuyeres.

A total amount of 961 tons of carbofer and 795 tons of light shredder fractions have been injected during the testing periods.

Since 1994, prepared plastics from different preparation methods have been injected, with a total above 1,200 tons.

Figure 3 shows the discontinuous injection equipment S.I.T. 2000 that has been used for the tests. Handling of substances has been performed with big bags (3).

In parallel to the tests on blast furnace 6, an equipment was developed for large-scale injection of solid matters with a

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Expérience d'utilisation d'agents réducteurs de substitution au haut-fourneau

J. Buchwalder, T. Fuchs, J. Hunger, T. Siepert
(EKO Stahl)

Les hauts-fourneaux 1 et 5 d'EKO Stahl sont équipés pour l'injection de fuel lourd. Le haut-fourneau 1 dispose également d'un équipement d'injection de solides.

En marche normale, le haut-fourneau 5 injecte 100 % de fuel lourd alors que le HF 1 a pour objectif d'injecter 100 % de plastiques agglomérés.

Historique du développement des injections d'agents réducteurs auxiliaires chez EKO Stahl

Dès 1993, des essais à grande échelle d'injection de granulats de plastiques ont été réalisés sur le haut-fourneau 6, essais qui se sont poursuivis jusqu'en 1995 avec d'autres matériaux tels que les résidus de broyage, des boues grasses ou des boues de vernissage.

Depuis 1994, plus de 1 200 t de plastiques préparés selon diverses méthodes ont été injectées. Une installation d'injection de 5 t/h sur 13 tuyères a été construite au haut-fourneau 3 et a démarré fin août 1996.

Mise au point de l'équipement d'injection

Pour utiliser une large gamme de matériaux, EKO Stahl a développé un système capable d'injecter à la fois des matériaux fins et des matériaux grenus ainsi que de les répartir de manière fiable entre les tuyères.

Deux systèmes d'injection permettent l'alimentation en phase dense de produits fins, en utilisant le système Koste validé pour le charbon pulvérisé, et une alimentation en phase diluée de matériaux grenus. Les solutions mises en œuvre permettent d'alimenter un nombre quelconque de tuyères, les lignes d'injection pouvant être mises en service indépendamment les unes des autres.

Chaque système possède 13 lignes de 70 m pour alimenter 13 des 15 tuyères du haut-fourneau, les deux tuyères proches du trou de coulée n'étant pas équipées.

Afin de permettre une marche en continu, le silo de dosage est alimenté par un silo de pressurisation lui-même relié à un silo de stockage intermédiaire relié au silo de stockage primaire par une ligne de 120 m de transport en phase diluée. Des extracteurs à vis transfèrent les granulats du silo de stockage sur des cribles qui éliminent les fractions supérieures à 10 mm. Les granulats criblés se déversent dans la trémie de chargement dont ils sont extraits au moyen d'un extracteur alvéolaire qui alimente la ligne de transport.

Injection de plastiques agglomérés

Les taux d'injection sont en augmentation régulière depuis la mise en service des installations en 1996. Les paramètres caractéristiques de la qualité des plastiques injectés, humidité, densité, teneur en chlore et cendres sont très stables. Pour assurer un bon transport, les spécifications sur la granulométrie sont 0 -10 mm et la fraction inférieure à 250 µm ne représente que 1 %. Pour une marche stable, il est préférable d'avoir un matériau à 50 % de fractions supérieures à 6 mm. Le taux d'injection de plastiques a atteint 65 kg/tf ce qui a permis de réduire à quasi zéro l'injection additionnelle de fuel lourd.

Le refroidissement résultant de l'injection de plastiques à faible température de vent est compensé par une forte suroxygénation qui améliore par ailleurs la productivité et permet une production annuelle de 550 kt de fonte. L'utilisation du gueulard à géométrie variable et d'un modèle de chargement contribue également à l'obtention de ce niveau de productivité.

Injection de graisses animales

Depuis mars 2001, des graisses animales sont injectées en mélange au fuel lourd sur le haut-fourneau 5. Avec une teneur en carbone de 76,5 % et une teneur en H_2 de 11,9 % , les graisses animales ont un PCI de 39 MJ/kg ce qui les rend très proches du fuel pour l'injection au haut-fourneau. Par ailleurs, leurs caractéristiques physiques (densité, viscosité, température d'inflammation) sont elles aussi très proches de celles des fuels auxquels elles se mélangent très facilement à une température de 80°C, ce qui permet de les utiliser sans préparation complémentaire. La faible teneur en chlore et la très faible teneur en soufre des graisses animales contribuent à la qualité de la fonte et à la régularité de marche du haut-fourneau. Les graisses animales représentent environ 25 % de la quantité totale d'agents réducteurs liquides injectés quotidiennement.

Développements futurs

L'utilisation d'agglomérats de plastiques revêt une grande importance pour la compétitivité future de la production de fonte chez EKO Stahl. La sidérurgie sera appelée à jouer un rôle de plus en plus actif dans le recyclage des véhicules usagés. En conséquence, on peut prévoir une augmentation de l'utilisation des résidus organiques provenant du recyclage des automobiles. Notre expérience d'injection au haut-fourneau montre que cette solution est viable mais une bonne préparation de ces matériaux, en particulier l'élimination du cuivre et du zinc qui sont valorisables par ailleurs reste indispensable.

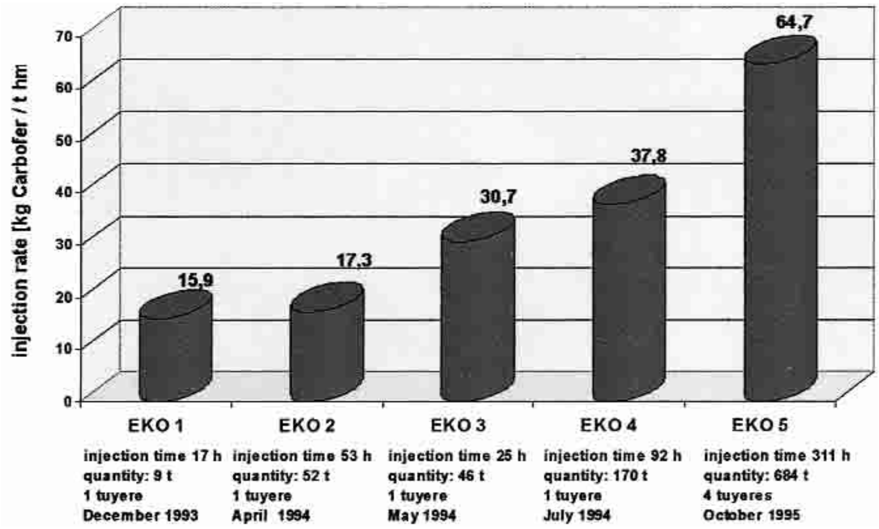

Fig. 1 – Alternative reducing agents injection of carbofer 1993-1995.

Fig. 1 – Substitution d'agents réducteurs par injection de carbofer, 1993-1995.

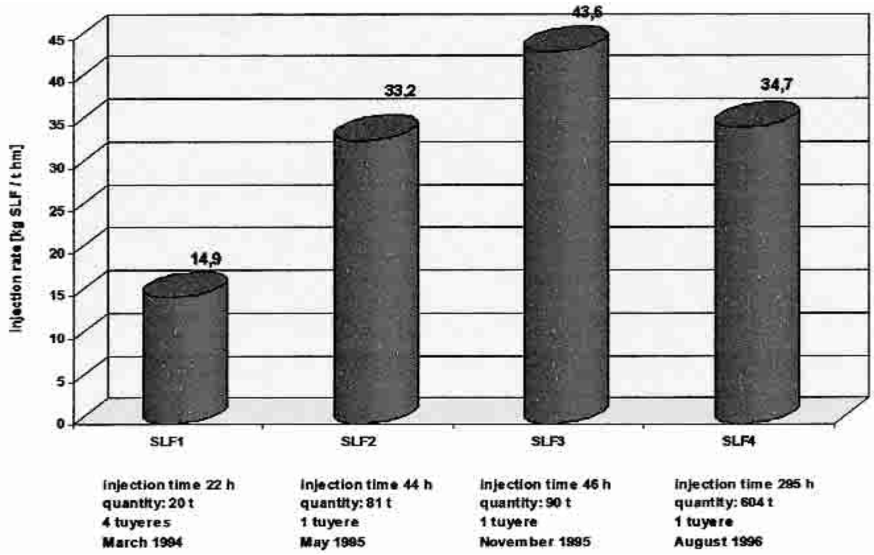

Fig. 2 – Alternative reducing agents injection of light shredder fraction 1994-1996.

Fig. 2 – Substitution d'agents réducteurs par injection de résidus de broyage, 1994-1996.

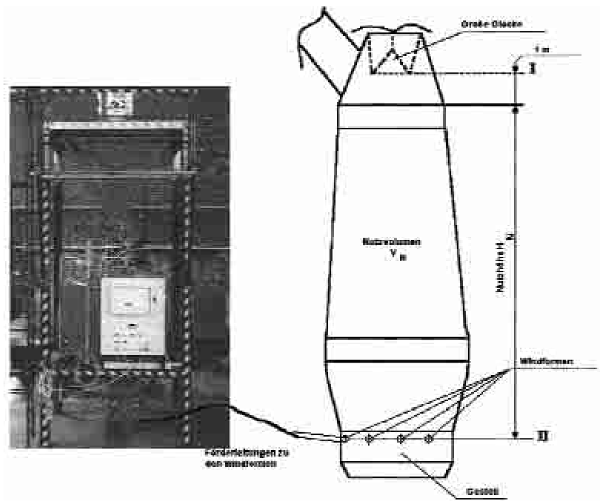

Fig. 3 – Scheme of the test injection installation at blast furnace 6.

Fig. 3 – Schéma du pilote d'injection au HF 6.

nominal capacity of 5 t/h through 13 tuyeres. At the end of august 1996, injection operation on BF 3 started-up with this system.

During the same period, with Deutschen Gesellschaft für Kunststoffrecycling (German Association for plastics recycling) continuous supply of mixed plastics agglomerate was agreed upon.

■ DEVELOPMENT OF SUITABLE EQUIPMENT OF INJECTING COARSE AND FINE-GRAINED SUBSTANCES INTO BLAST FURNACE TUYERES

For being able to utilize a broad spectrum of potential additional reducing agents, the aim was to develop injection equipment that could dose and feed fine-grained and granulated waste products equally to all the tuyeres with a high reliability.

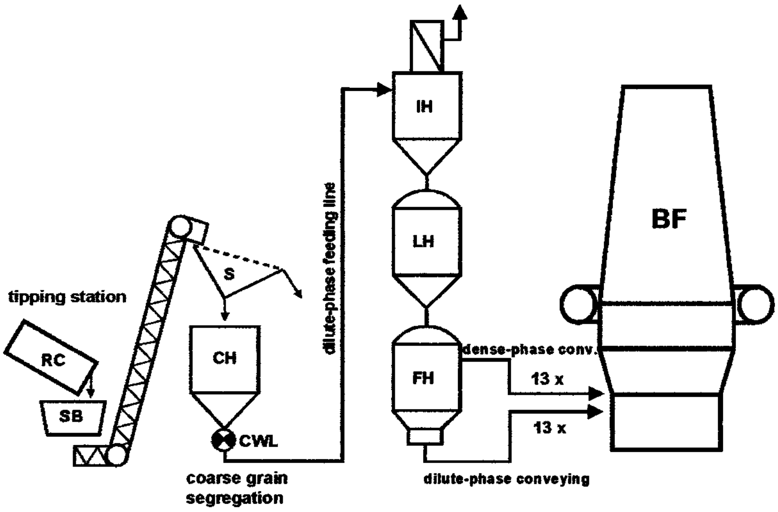

Fig. 4 – Scheme of the installation for injection of granulates and powders.

Fig. 4 – Schéma du pilote d'injection de poudres et granulats.

The developed technical solutions allow providing practically any number of tuyeres. In this connection, any number of feeding lines can be switched on and off independently from each other.

In this special case, two separate systems with 13 feeding lines each to 13 of totally 15 tuyeres were implemented with a length of 70 m. Thus, each tuyere, but for the tuyeres next to the tap hole of the blast furnace, could be provided with powdered materials in dense-phase conveying (e.g. coal dust) or coarse-grained materials in dilute-phase conveying. This especially applies to different prepared residuals.

For providing continuous conveying, the feeder hopper gets filled with the help of a lock hopper that in turn is fed from an intermediate bunker. The latter is fed by means of a 120 m long dilute-phase feeding line from a storage bunker system (*fig. 4*).

For this purpose, in one feeder hopper, two conveying systems were installed, a dense-phase conveying system according to the proven KOSTE method for coal dust injection (1) and a dilute-phase system for conveying coarse-grained materials. In this connection, the problem had to be solved to feed and dose the coarse-grained materials (grain size up to 10 mm) symmetrically and with a satisfactory distribution. For this purpose, relatively small conveying volumes per feeding line (300-500 kg/h) have to be fed into a large number of feeding lines.

For avoiding any wear problem during dosing, pneumatic dosing and conveying principles have been utilized exclusively.

This storage bunker system is designed specifically for coarse-grained granulates and it is at present used for mixed plastics granulates. The storage bunker is supplied by closed roll containers, that are parked at a storage place (*fig. 5*).

On request, by means of special vehicles, the roll containers are put onto a tipping device, that simultaneously and independently from each other empties two containers into the storage bunker (*fig. 6*). From the storage bunker by means of screw feeders, the granulate is fed onto a vibrating screen, where the coarse constituents, above 10 mm in size, are screened out (*fig. 7*). Screened granulate falls into a charging hopper, from where a cellular wheel lock feeds the granulate into the mentioned dilute-phase line.

Fig. 5 – Storage of agglomerated mixed plastics container parking place.

Fig. 5 – Aire de stockage des containers de mélanges de plastiques agglomérés.

Fig. 6 – Plastics unloading station at blast furnace 1, container tipping station.

Fig. 6 – Poste de déchargement et de déversement des plastiques au HF 1.

Fig. 7 – Plastics unloading station, coarse grain segregation.

Fig. 7 – Poste de déchargement des plastiques, séparation des fractions grossières.

■ USE OF ALTERNATIVE ADDITIONAL REDUCING AGENTS IN PRESENT OPERATION MODE

Agglomerated mixed plastics

Starting the injection at blast furnace 3 at mid 1996, injection rates could be increased continuously step by step over the years (*fig. 8*).

This gradual increase is directly connected with the extension of collection activities of the Dual System Germany and the improvement of agglomeration capacities in Germany.

About half of the 30,000 tons per year of agglomerated mixed plastics required by EKO Stahl is produced in a preparation plant in Eisenhüttenstadt that belongs to Alba Recycling Ltd. The second half is supplied by different firms of the Federal Republic.

Figure 9 documents the development of quality parameters (according to the DKR specification) of the agglomerated mixed plastics, e.g. humidity, bulk density, chlorine content and ignition residue over a 2 years period from July 1999 to July 2001.

Except for the increase of ignition residue by about 0.6 %, a high constancy of parameters can be seen, e.g. for the chlorine content. This could be reduced from high values in the years before to a technically acceptable value of 1.2 % by efforts of the preparation plants.

To maintain the pneumatic conveyability of agglomerated mixed plastics, grain size distribution is of great importance (*fig. 10*). According to the specification, the grain size ranges from 0 to 10 mm. In our experience, the proportion of particles below 250 µm is limited to 1 %.

For a stable injection under the EKO Stahl conditions, it has been proved that about 50 % of the injected material has an upper grain size of 6 mm. Therefore, additional preparation measures have to be taken.

Along with the blow-in of blast furnace 1 in May 2001, the switching-over of the injection equipment to blast furnace 1 was performed.

This gave the opportunity to introduce important technical improvements and extensions. In addition to the renewal of pressure vessels, the complete replacement of electrical and automation equipment was executed (*fig. 11*). The control

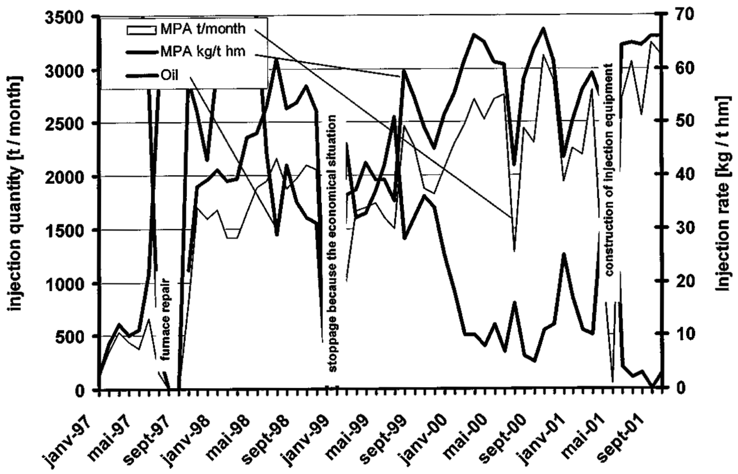

Fig. 8 – Monthly injection quantity of agglomerated mixed plastics and development of the reducing agent consumption.

Fig. 8 – Taux mensuel d'injection de plastiques et évolution de la consommation d'éléments réducteurs.

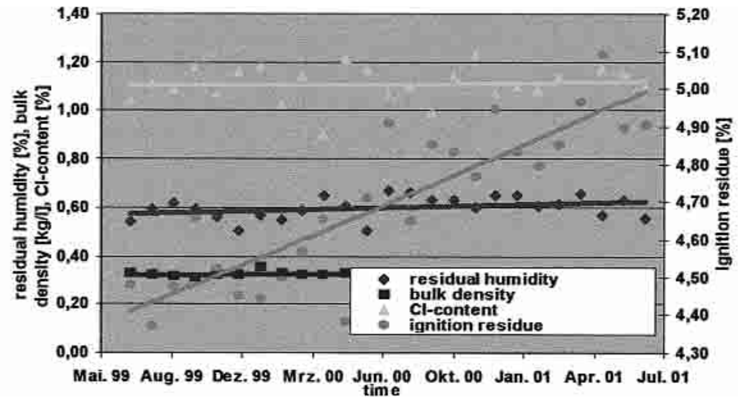

Fig. 9 – Evolution of the properties of mixed plastics for injection from June 1999 to July 2001.

Fig. 9 – Évolution des caractéristiques des mélanges de plastiques injectés entre juin 1999 et juillet 2001.

of the injection facility is performed with a software user interface. The main important extension is the improvement of nominal line performance to 8 t/h.

These modifications resulted in a further improvement of the line stability.

Following a sharp start-up curve during commissioning of the injection equipment, the agglomerated plastics injection rate was increased to 65 kg/t of hot metal (*fig. 8*). Due to this measure, the additionally injected quantity of heavy oil could practically be reduced to zero. With this injection rate, a monthly quantity of mixed plastics of 3,000 tons was reached.

The significant improvement of line stability is also documented in *figure 12*.

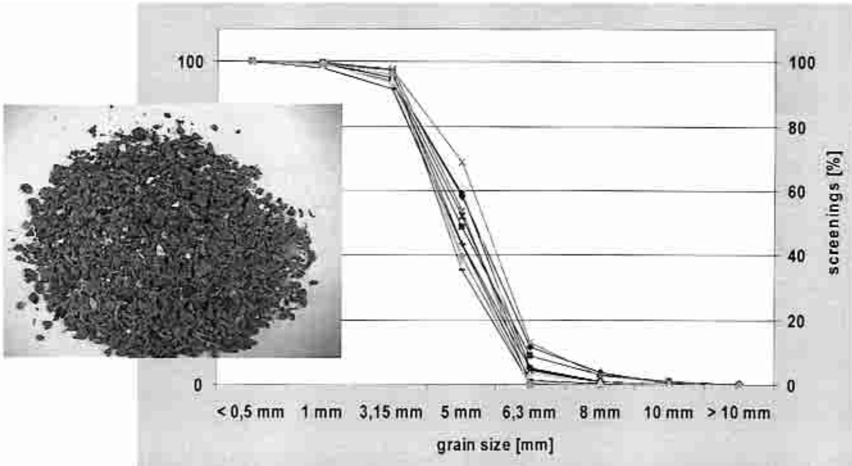

Fig. 10 – Example of particle size distribution of agglomerated mixed plastics at EKO Stahl.

Fig. 10 – Exemple de distribution de la granulométrie des plastiques injectés à EKO Stahl.

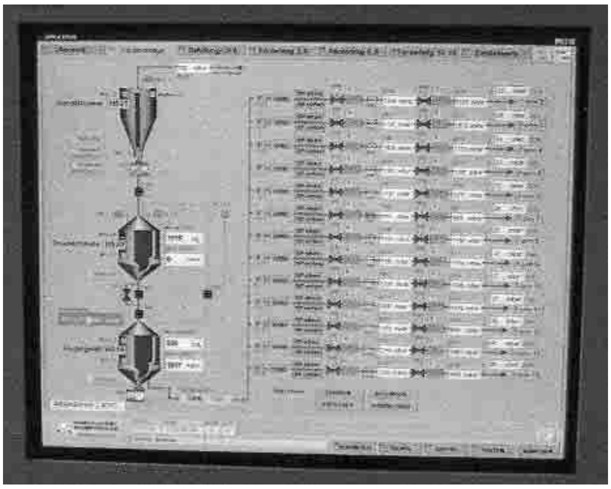

Fig. 11 – Complete replacement of electrical and automation equipment.

Fig. 11 – Remplacement complet de l'équipement électrique et des automatismes.

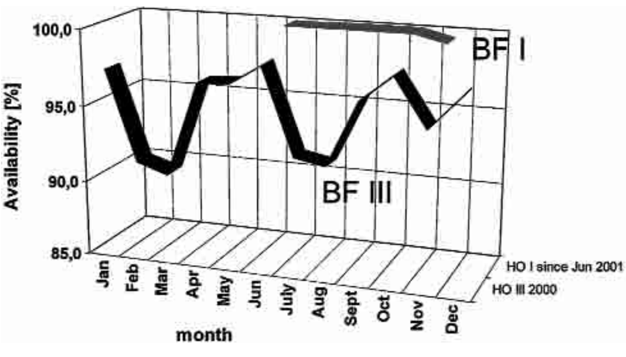

Fig. 12 – Comparison of availability of agglomerated mixed plastics injection facility, BF 3 (2000) and BF 1 (2001).

Fig. 12 – Comparaison du taux de marche de l'injection de plastique au HF 3 (2000) et au HF 1 (2001).

Already on blast furnace 3, a line availability of about 95 % could be achieved.

It is the objective for the line on blast furnace 1, to increase this value to 97 %. This stability has also a significant impact on the parameters of blast furnace 1 (*tabl. I*).

To compensate for the effect of high plastics injection rates and low hot blast temperature, it is possible to operate with relatively high oxygen enrichment.

This results in the performance-increasing effect that enables an annual production of 550,000 tons.

Additional support is also given by using movable armour and a burden distribution model for the double-bell top.

Animal fat

Since March of 2001, in addition to heavy oil, animal fats from animal body utilization are injected into the blast furnace as reducing agents through the oil injection equipment of blast furnace 5.

With a carbon content of 76.5 % and a H_2 content of 11.9 %, animal fats show a calorific value of 39,000 kJ/kg (*tabl. II*). Therefore, from the point of view of utilization as reducing agent in the blast furnace, their material properties are near to that of heavy oil.

As animal fat can be mixed easily with heavy oil at an operation temperature of 80°C and as the physical properties, like density, viscosity and ignition point also are in good conformity, animal fat mixed with fuel oil can be used without any further preparation. Some problems may appear in the case of animal fat that contains solid impurities. Additionally installed filters avoid failures of the injection equipment and keep a smooth injection operation.

TABLE I : Current values for blast furnace 1.

TABLEAU I : Paramètres actuels du haut-fourneau 1.

	June	July	August	Sept.	Oct.
Production Itlmonth)	42,124	46,810	39,634	48,339	47,258
Average daily production (t/d)	1,530	1,584	1,487	1,627	1,639
Coke consumption (kg/thm)	419	394	423	409	423
Plastic [kg/thm)	65	68	67	66	66
Oil (kg/thm)	4	2	3	0	3
O_2-addition (m^3/thm)	28	36	35	30	36
O_2-enrichement (%)	1.87	2.48	2.28	2.08	2.49

TABLE II : Comparison of characteristic data for animal fat and heavy oil.

TABLEAU II : Comparaison des propriétés des huiles lourdes et des graisses animales.

	Animal fat	Oil
Calorific value	39,000 kJ/kg	40,000 kJ/kg
Density (15°C)	0.92 - 0.93 g/cm^3	0.85 - 1.02 g/cm^3
Flash point	> 180°C	> 100°C
S-content	< 0.004%	2.2 %
Cl-content	< 0.002 %	< 0.005 %

The low chlorine content and significantly lower sulphur content of animal fat bring advantages for the hot metal production.

Analogous to a part of the heavy fuel oil, the fat is supplied in tanker trucks and filled into feeder tanks (*fig. 13*). Every day, 25 % of the used liquid reducing agents at the blast furnaces is animal fat (*fig. 14*).

By the end of August 2001, already 10,800 tons of animal fat could be injected as reducing agent.

Fig. 13 – Un-loading of heavy oil and animal fat feeder tanks of the oil injection facility.

Fig. 13 – Déchargement et stockage des huiles lourdes et des graisses animales pour l'injection.

■ FUTURE DEVELOPMENT

The use of agglomerated mixed plastics as reducing agents will be of great importance for the efficiency of hot metal production in Eisenhüttenstadt in the future.

It has to be expected that the steel industry, in co-operation with the automotive sector, will participate more actively in the recycling of end of life vehicles. Therefore, it has to be assumed that the problem of utilizing organic materials from vehicle recycling will play a more important role. Our experience with injection indicates that the utilization in the blast furnace is a feasible solution. However, careful preparation of light shredder fraction, especially the separation of copper and zinc, being valuable raw materials themselves, is an important prerequisite.

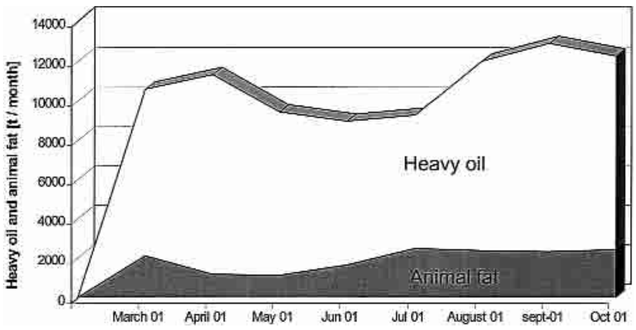

Fig. 14 – Oil and animal fat consumption at blast furnaces of EKO Stahl from March to October 2001.

Fig. 14 – Injection de graisses animales et d'huiles lourdes aux hauts-fourneaux d'EKO Stahl entre mars et octobre 2001.

■ REFERENCES

(1) HUNGER (J.) – Einsatz ostdeutscher Braunkohlenbrennstäube und Reststoffe über die Windformen des Hochofens. Dr.-Ing. Diss., TU Bergakademie Freiberg (1997).

(2) JANKE (D.), KRÜGER (W.), KALINOWSKI (W.), SCHWAGER (M.) – Verwertung von ölkontaminierten Walzzunderschlämmen und Shreddermüll über Hochöfen. Abschlußbericht, Freiberg, Deutsche Bundesstiftung Umwelt (february 28, 1997).

(3) JANKE (D.), BUCHWALDER (J.), HUNGER (J.), KRÜGER (W.), KALINOWSKI (W.), LETZEL (D.) – Verwertung ölhaltiger Walzzunderschlämme und der Shredderleichtfraktion von Altautos im Hochofen. Tagungsband XLVI. Berg und Hüttenmännischer Tag, Freiberg (1995), p. 120-133.

(4) SCHEIDIG (K.) – 6 Jahre KOSTE-Verfahren in der Maxhütte Unterwellenborn. Betriebserfahrungen und internationaler Vergleich beim Kohleeinblasen in den Hochofen. *Neue Hütte* 35 / 7 (1990), p. 241-245.