Analysis of State and Possibilities for a Profitable Production of Steel in Croatia

Analiza stanja in možnosti za dobičkonosno proizvodnjo jekla na Hrvatskem

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The production and development of the integrated Sisak Ironworks since 1973 are presented. The Ironworks participates with 80% in the total rolling stock production in Croatia. The development of the world steel production is presented and compared to the circumstances in Croatia. The feasible manufacture level of rolled products in Croatia is shown and discussed considering the low price steel manufacturing in electric arc furnaces. A comparison between the production in electric arc furnace and a feasible steel manufacture in existing blast furnaces and converters with enlarged share of steel scrap is prepared with the aim to contribute to a better insight into the possibilities of a more profitable steel manufacturing in Croatia.

Key words: steel production, state, possibility, Croatia

Predstavljeni sta proizvodnja in razvoj integralne železarne Sisak od leta 1973. Železarna Sisak je proizvajala 80 % valjanih izdelkov na Hrvatskem. Razvoj svetovne proizvodnje jekla je primerjan z razmerami na Hrvatskem. Dosegljiva proizvodnja valjanih izdelkov je pripravljena in analizirana z upoštevanjem nizke cene v električnih obločnih pečeh. Pripravljena je primerjava med proizvodnjo v elektro obločnih pečeh in proizvodnjo, ki jo je mogoče doseči v obstoječih plavžih in konvertorjih s povečanim deležem jeklenih odpadkov z namenom boljše ocene možnosti za bolj dobičkonosno proizvodnjo jekla na Hrvatskem.

Ključne besede: proizvodnja jekla, stanje, možnosti, Hrvatska

1 Introduction

The basic deficiency of ferrous metallurgy in Croatia is the unprofitable low priced steels manufacture, which has also prevented the development of technology. About 20 years ago important improvements took place in converter steel processing, from the increase in volume of blast furnaces (BFs) and converters, which greatly reduced the production prices to the recent increase of the share of scrap in converter charge from 25% to 6O%. This has been achieved by preheating the charge and addition of coke in converters. The basic reason for increasing the share of scrap is the cheaper processing in converters than in electric arc furnaces (EAFs), particularly small ones. The increased share of scrap, always less expensive than pig iron, permitted to stop small and out of date BFs. EAFs were earlier used for manufacturing of quality steels at acceptable prices. The increased capacity of EAFs and the introduction of secondary steel processing enabled the manufacturing of low priced steel with acceptable profit because of the greatly increased productivity. At present, EAFs melting takes less than one hour, while the further processing is made in ladles.

2 Projection of development of Sisak Ironworks since 1973

Until 1973 two BFs a with volume of 150 m^3 each produced pig iron, which was mostly used in open hearth furnaces (OHFs) and less in EAF. After 1973, the volume of both BF was enlarged up to 202 m^3 and the production increased by about 16%. Steel was manufactured in two 145-ton OHFs charged with 50% of molten pig iron and 50% of scrap, and in one 30-ton EAF. Parallelly, the processing was intensified by blowing of oxygen, which required the construction of an oxygen plant in 1973. In 1974 and 1975 oxygen blowing equipment was installed and the production of steel in OHFs increased. In 1973 a continuous caster with a capacity of 500000 tpy was put in operation and the size of rolling billets was altered. In 1987 a new sinter plant with a capacity of 550000 tpy was put in operation as well. In the long term projection of steel production started in 1970 the construction of 1200 m^3 BF at the seaside, economically correct but ecologically questionable, and one of the same size in Sisak were planned. The coke plant with the capacity of 850000 tpy was put in operation in 1978. Since the financial funds for the construction of BF were not disponible, in 1980 the manufacturing of steel in EAFs began to be considered.

3 Development of world-wide steel technology since 1970

The basic reason for the decrease of OHFs production after 1970 was the poor economy when compared to the steel production in converters and EAFs. The improvement of converter processing was made possible because of BFs (up to 5500 m^3) and converters giving much higher production and productivity, as shown in **Figure 1**[1]. It has to be noticed that the productivity per

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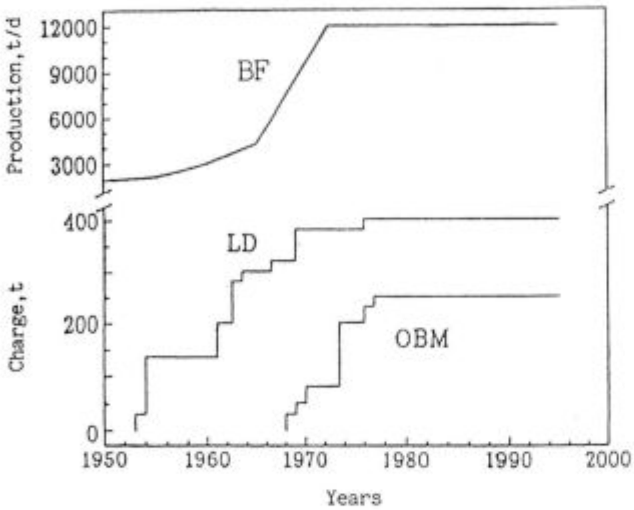

Figure 1: Evolution of production of BFs (upper part of the picture) and weight of converters (lower part of the picture) from 1950

Slika 1: Razvoj proizvodnje plavžev (zgornji del slike) in kapaciteta konvertorjev (spodnji del slike) od leta 1950

production unit was also increased by about three times in the years from 1965 to 1972. By charge preheating and coke addition into converters the energy balance was improved and thereby the charging of solid input increased up to 60%[2] which further increased the rentability. New development diminished the consumption of coke in a production line BF - converters under 300 kg/t steel, as well as other costs. Parallelly, improvements in EAF were also introduced. The power of transformers was increased and charge preheating introduced. The ladle metallurgy (secondary steel making) enabled the discharge of furnace after melting[3], diminished the con-

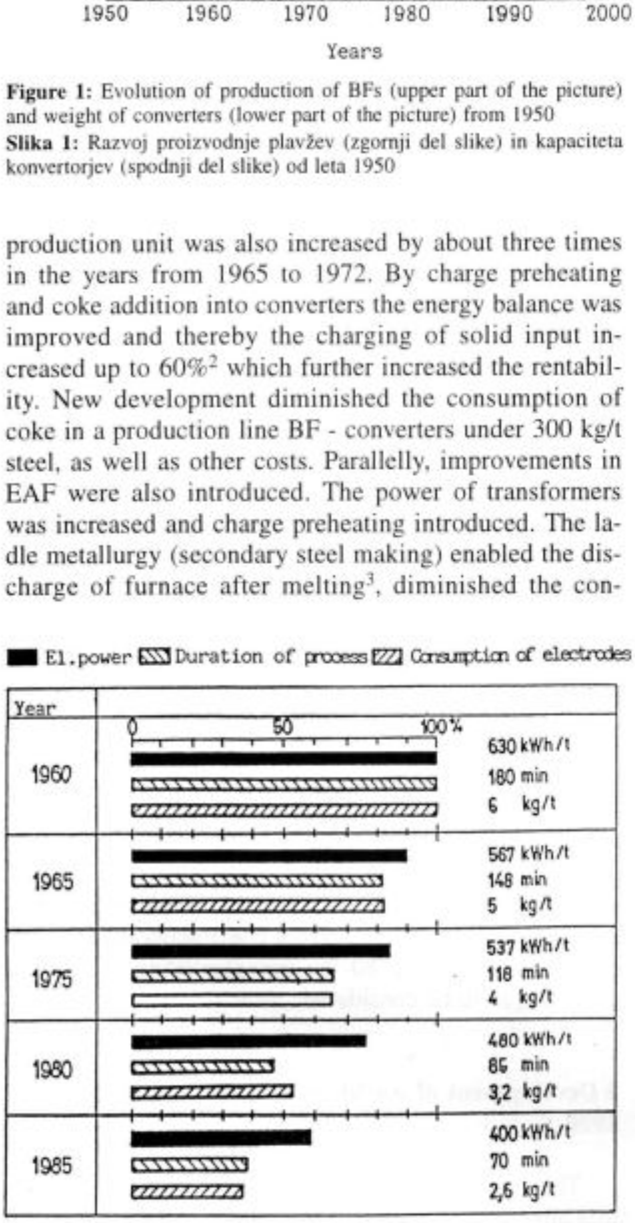

Figure 2: Decrease of the consumption of electric power, shortening melting time and decrease of consumption of electrodes with the development of high efficiency EAFs

Slika 2: Zmanjšanje porabe električne energije, skrajšanje časa taljenja in zmanjšanje porabe elektrod z razvojem učinkovitih elektro obločnih peči

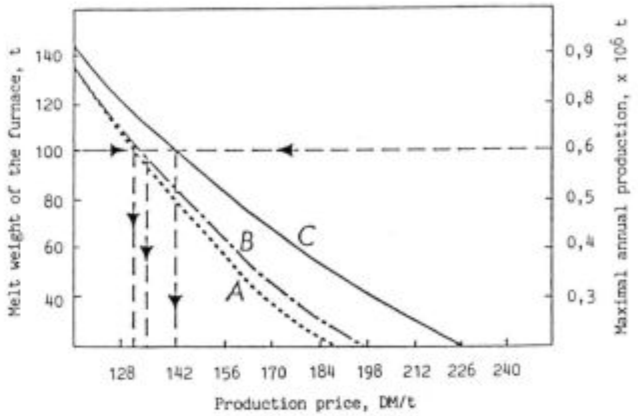

Figure 3: Relationship furnace capacity versus production price for different levels of salaries. A - production costs without salary, B - gross salary of 700 DM per worker, C - gross salary of 4200 DM per worker

Slika 3: Razmerje med kapaciteto peči in proizvodna cena za različne nivoje plač. A - proizvodni stroški brez plač, B - brutto plača 700 DEM, C - brutto plača 4200 DEM

sumption of energy and electrodes, and shortened the melting time as shown in **Figure 2**.

A number of improvements in the electric steel production has increased the rentability of the process and since then low priced steel are produced in average EAFs[4,5,6,7,8]. The influence of EAF size on production price is shown in **Figure 3**[5,6]. Curve **A** refers to the production costs without salary, curve **B** to a gross salary of 700 DM and curve **C** to a gross of 4200 DM per worker and month.

All efforts to increased the rentability of open hearth steel elaboration by oxygen injection proved to be unsuccessful. Oxygen intensification is used either by injection of enriched air during charging and heating or by injecting oxygen during melting and refining. Air is enriched with oxygen up to 27% and the time of charging and soaking is diminished up to 30%. Further air enriching leads to no shortening of charging and soaking time because of energy consuming dissociation of gas components CO_2 and H_2O in the furnace. The decarburization rate due to oxygen injecting into the melt depends upon open hearth size[9]. In **Figure 4**, the necessary heat flow in dependence upon open hearth capacity and the percentage of slag in relation to the mass and rate of decarburization are shown. Directions in the figure represent heat flow because of combustion of CO evolving from the melt at various carbon combustion rates (V_c).

Curve **A** in **Figure 4** shows the maximal possible heat flow, curve **B** the flow with 15% of slag, curve **C** the flow with 6% of slag, and curve **D** the heat flow for keeping the empty furnace at operation temperature. In smaller-size furnaces the decarburization rate (V_c) of about 2,5% C/h while in greater furnaces the rate of 1% C/h can be reached. Higher decarburization rates with heat flows greater than that shown by the curve **A** would lead to a furnace pressure greater than that allowed and

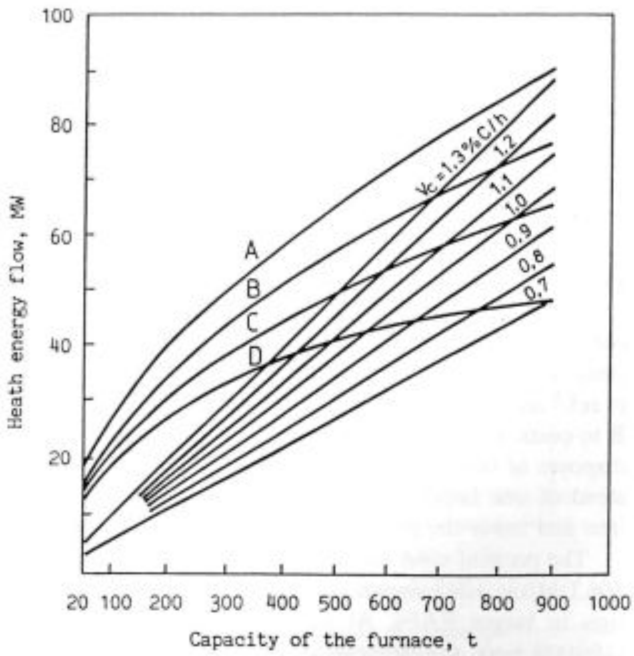

Figure 4: Relationship heat flow versus the capacity of OHFs for different decarburization rates and different quantities of slag. A - maximally possible heat flow, B - heat flow with 15% of slag, C - heat flow with 6% of slag, D - heat flow at operating temperature of the empty furnace

Slika 4: Razmerje med toplotnim tokom in kapaciteto Siemens Martinovih peči za različne hitrosti razogljičenja in različne količine žlindre. A - največji toplotni tok, B - toplotni tok pri 15 % žlindre, C - toplotni tok pri 6 % žlindre, D - toplotni rok pri prazni peči

cause several consequences. The converter decarburization rate reaches about 8% C/h. The total increase of maximal productivity of steel by oxygen injection in OHF is about 40%. The basic reason for stopping the open hearth steel production is the low productivity, especially in small-size OHFs, hence higher costs than by converter and electric furnace processing but not - as sometimes claimed - because of higher costs of energy.

4 Croatian and world steel production since 1973

The production of steel in Sisak Ironworks until 1973 was about 350000 tpy, 280000 tpy in OHFs and 70000 tpy in EAF. Steel processing plants needed about 550000 tpy of steel, therefore, 200000 tpy were purchased. With the aim to become less dependent of external suppliers, the steel making plants were reconstructed to increase the production of steel up to 410000 tpy. BFs were reconstructed and their size enlarged from 150 to 202 m^3, which increased the pig iron production by about 16%. The planned increase of open hearth production has never been achieved. On the contrary, it remained on the same level as before the reconstruction, while manufacturing costs increased because of inefficient oxygen injecting as well as more consumption of refractory lining and ferroalloys, and smaller output. Greater consumption of refractory lining and smaller slopping is a normal consequence of oxygen injection in the melt that has to be economically justified by increased manufacture. Greater consumption of ferroalloys, is a consequence of wrong utilization of injected oxygen. Oxygen was also injected during the melting process. This was a non competent decision because of the small share of molten charge. It was not possible to coordinate the temperature in some melts with the carbon content at the end of the refining process. The rate of decarburization was 1,0 to 1,5% C/h and ferroalloys were added also with the aim to heat up the melt to the necessary temperature[10].

If the planned production increase had been achieved, it would have been failure from the stand point of increase of economy and of profitability. Namely, the share of expensive pig iron was increased by about 16% and, since it was produced in out-of-date BFs, it was 2,5 times more expensive than steel scrap.

Back in 1973 BF units were world-wide producing up to 12000 tpd - the Sisak unit only 300 tpd - and converters about 350 tph. By the planned enlargement of OHF the efficiency would have been 28 tph per OHF. The productivity of EAFs was then about 80 tph and there was a clear tendency for further enlargement so that to day productivity of larger EAFs reaches up to 200 tph. The only way to increase the quantity of steel up to about 200000 tpy using the existing BFs was to built up oxygen plant and an adequate converter using 200000 tpy of molten pig iron. This could have been achieved with less investments than through open hearth process intensification by oxygen. Scrap could have been used both, in OHFs without addition of oxygen and in the 30-ton EAF, and achieve the needed 500000 tpy of steel[8]. This version was not considered although it would have given the wanted increase of production as well as an increase of efficiency and profitability, although still under world levels. That efficiency and profitability were not sufficiently considered is evident. The planned construction of two BFs of about 1000 m^3 was unprofitable because furnaces of about 3000-4000 m^3 were already in operation in several countries.

According to the criteria of profitability Sisak Ironworks had no conditions for steel manufacture by means of BF and converters. A 4000 m^3 BF would produce of about 9000 tpd of pig iron and would require three times more raw materials to be transported to Sisak.

Beside the increased transport costs, the railway capacity in existence was also questionable. The only profitable orientation for the manufacturing of low priced steels required by the actual structure of products are 100-ton EAFs which achieve a production cheaper by about 70 DM/t than in 45-ton furnaces (**Figure 3**). The company policy was that it is megalomanic to build large production units for low price steel although such units remarkably increase the profitability. "Megalomanic products", in which the price of steel sometimes participates more than 80%, were never abandoned. The inefficiency cannot be significantly improved in the existing rolling mills with their actual products because the price difference between steel manufactured with modern processes and steel produced in Sisak Ironworks is about 280 DM/t.

5 Possible production of steel for rolled products in Croatia

The present steel production in EAFs in Croatia is achieved in three furnaces (Sisak and Split) with the maximal production of about 200000 tpy. This makes it expensive (great consumption of energy and electrodes, maintenance costs and costs for operators' salaries) in relation to great EAFs producing up to 1500000 tpy of steel. At the production of 600000 tpy, the production per worker is three times greater. The production of about 200000 tpy in smaller EAFs would be more expensive than the production of 600000 tpy in a 100-ton EAF by about 84 DM/t of steel. The processing costs in EAFs for 200000 tpy of steel would be about 224 DM/t, while, by 600000 tpy would be about 140 DM/t[11]. For this reason world-wide facilities greater than 500000 tpy are used for low priced steel production[4]. The casting costs of a greater quantity of steel are also lower. In **Figure 5**[12], the costs of production of since 1982 and of steel scrap in Germany are shown. The evolution of costs is also valid for steel plates and welded pipes, which have a similar price as concrete steel. The tendency of costs lowering is stronger than that for the prices of steel scrap used in EAFs. Ever smaller differences between the price of charge and costs of production are met in larger EAFs with capacity of (0,5 - 1,0) x 10^6 tpy (mini Ironworks)[11]. Maximal pig iron production in BFs in Sisak Ironworks is 230000 tpy. Using converters, preheating the converter charges, and injection of coke, as already mentioned, 50% of steel scrap could be charged and that would enable a production of about 400000tpy of steel.

At pig iron price of 448 DM/t (price when BFs were in operation) and at the price of 131 DM/t of scrap in **Figure 5** in 1991, the total charge price is 448 x 0,5 + 131 x 0,5 = 289,5 DM/t. The processing costs in 50-ton converter with charge preheating are about 77 DM/t of steel, as shown in **Figure 6**, which was drawn using data in ref.[3] and [13]. Curve **A** refers to costs without and curve **B** to costs with charge preheating. Unfortunately Croatia disposes of two small and out-of-date BFs of 202 m^3 instead of one larger-sized, which could produce cheaper iron and lower the price of steel products.

The price of steel scrap and its processing costs about 506 DM/t in 1992 shown in **Figure 5** refer to the production in larger EAFs. At small steel producing EAFs (200000 tpy), the processing costs in EAFs would be higher by about 84 DM/t. Steel casting and producing costs are also lower at higher manufacturing. At smaller steel production by the electric arc technology the costs are about the same as the costs of 50% charges consisting of molten pig iron from the existing BFs and 50% converter preheated and processed solid steel scrap.

Using the data in **Figure 3** and **Figure 6** the costs of charging and steel making have been estimated and

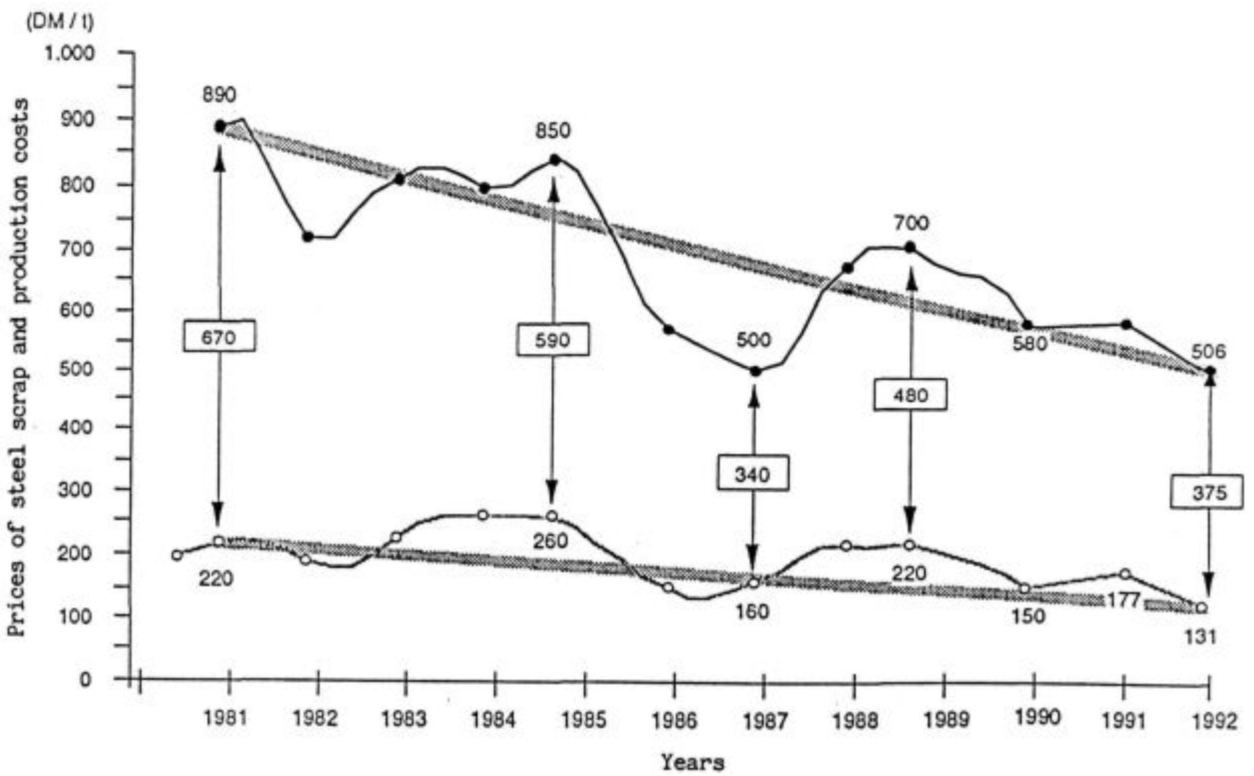

Figure 5: Survey of production costs for the manufacture of concrete iron in EAFs and prices of steel scrap from 1981 to 1992
Slika 5: Pregled stroškov za izdelavo betonskega jekla v elektro obločni peči in cena jeklenega odpadka med leti 1981 in 1992

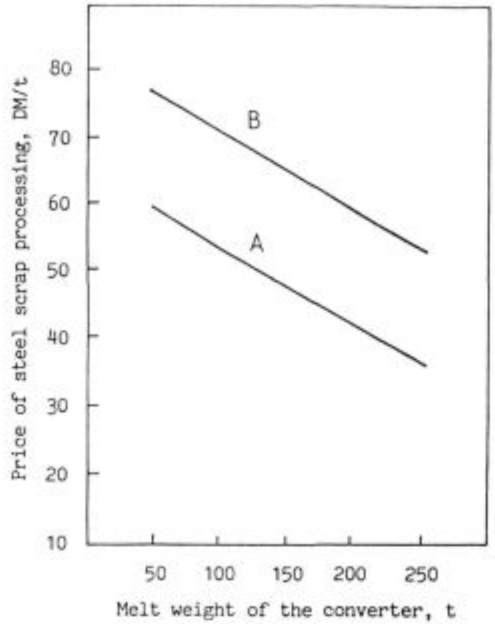

Figure 6: Price of steel scrap processing in dependence on converter melt weight. A - costs without charge preheating, B - costs with charge preheating

Slika 6: Cena jeklenega odpadka v odvisnosti od teže konvertorske šarže. A - cena brez in B - cena s predgrevanjem vložka

shown in **Figure 7**. Directions **A** refer to EAF production of 600000 tpy. The dashed lines refer t the monthly gross salary of 700 DM per worker and the full-lines to gross salary of 4200 DM per worker. In other cases (**B**, **C**, **D**, **F**) dashed lines refer also to a salary of 700 DM per worker and full lines to 4200 DM per worker. The lines **B** refer to the production of EAF of 200000 tpy, and **F** to 100000 tpy. The lines **C** refer to the production in the existing 202 m^3 BFs and a steel charge of 50% of molten pig iron and 50% of steel scrap in 50-ton converters with the salary of 700 DM by pig iron price of 448 DM/t, and with the salary of 4200 DM by pig iron price of 504 DM/t. The line **D** refers to the production of pig iron in large BFs and increased share of steel scrap from 25% to 50% by pig iron price of 280 DM/t[13], and pig iron - steel scrap shares of 50% to 50% in 250-ton converters. The line **E** refers to the limit price of steel scrap which is equal to the pig iron price from larger BFs. Above this price it is not economic to charge steel scrap in converters using pig iron from large BFs. In **Figure 7**, the difference of charge costs and costs of it processing into steel for EAFs of various size as well as converters using pig iron from small and big BFs is shown. It is evident that the costs of charge and it processing into steel are the lowest by steel production of 600000 tpy in 100-ton EAF at steel scrap price below 150 DM/t. At steel scrap price above 150 DM/t, the production is the cheapest in converters using large BFs pig iron. Finally, the production of steel in small-size BFs (202 m^3) and converters (50-ton) is cheaper than the production of 100000 tpy of steel in EAF. The production of 200000 tpy in EAF is an option to the production in the existing small-size BFs and 50-ton converters with 50% of steel scrap by scrap price greater than 180 DM/t.

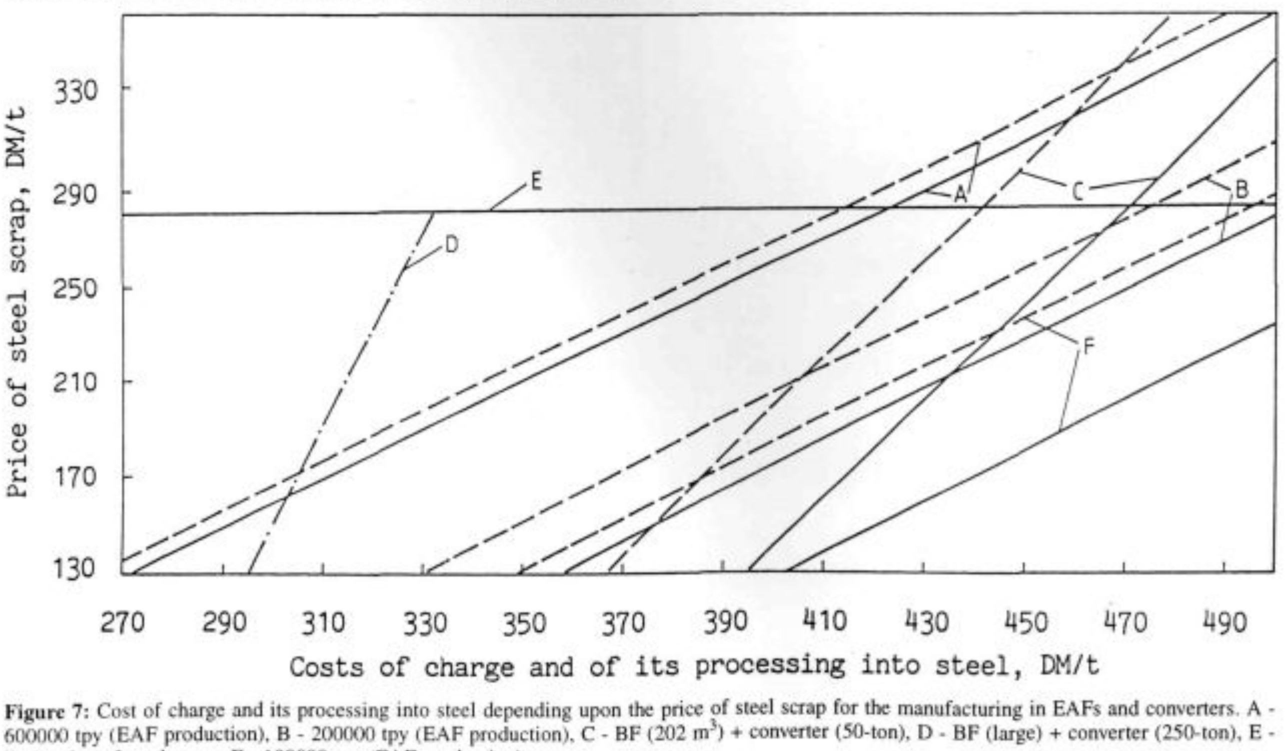

Figure 7: Cost of charge and its processing into steel depending upon the price of steel scrap for the manufacturing in EAFs and converters. A - 600000 tpy (EAF production), B - 200000 tpy (EAF production), C - BF (202 m^3) + converter (50-ton), D - BF (large) + converter (250-ton), E - limit price of steel scrap, F - 100000 tpy (EAF production)

Slika 7: Cene vložka in izdelave jekla v odvisnosti od cene jeklenega odpadka za proizvodnjo v elektroobločnih pečeh in v konvertorjih. A - 600.000 t letne proizvodnje v elektroobločni peči, B - 200.000 t letne proizvodnje v elektroobločni peči, C - plavž (202 m^3) + 50 t konvertor, D - velik plavž in 250 t konvertor, E - mejna cena jeklenih odpadkov, F - 100.000 t letne proizvodnje v elektroobločni peči.

6 Conclusion

The development of ferrous metallurgy in Croatia was compared to that in the world. It is evident that the development studies have failed because they led to the decision to reconstruct small BFs with the production of 300 tpd giving only an insignificant increase of production of 16%, while several BFs producing 12000 tpd were in operation. The intensification of processing in out-of-date OHFs with oxygen injection was introduced although in other countries such furnaces were abandoned. Every objective analysis would have proved that such a production is more expensive. It seems, therefore, that efficiency and rentability were no real intention by the reconstructions but merely the increase of the produced volume at any price. The quantity of steel could have been increased only by introducing adequate converters using molten pig iron from unreconstructed BFs and operation in OHFs could have been continued using cheaper solid charge. However, this version has not been considered at all, although it would have certainly increased the production - which was the goal - and the economics, yet, under the level of operating modern BFs and converters. At that time modern BFs had a production as much as twice cheaper than the BFs in Sisak.

If Republic of Croatia decides in favour of ferrous metallurgy as a strategic industrial branch, it is necessary to integrate all steel production in one EAF. This solution would significantly increase the efficiency of the production which should according to **Figure 7** achieve about 600000 tpy. The integration of the existing production in three small EAFs of about 200000 tpy has an argument in the existing BFs and already constructed converter. Compared with the low production of EAFs this option is preferred provided that the price of steel scrap is above 131 DM/t.

The production of steel in a small EAF (200000 tpy) and the production in small BFs and 50-ton converters with 50% steel scrap are less efficient than the production in 100-ton EAF of about 600000 tpy.

7 References

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