THE DESULPHURISATION COST CHANGE
IN AN INTEGRATED IRON AND STEEL PLANT:
AN EMPIRICAL ANALYSIS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
ÇANKAYA UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF MANAGEMENT

SEPTEMBER 2006

Title of the Thesis : **The Desulphurisation Cost Change In An Integrated Iron And Steel Plant: An Empirical Analysis**

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ABSTRACT

THE DESULPHURISATION COST CHANGE
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September 2006, 62 pages

Desulphurisation is an important phase in the iron and steel production process, and the cost of desulphurisation takes an important part in the total cost of production. In İsdemir it was observed that the monthly 2005 desulphurisation costs became drastically increased in comparison to monthly 2004 desulphurisation costs. The subject matter seems to give a good example of solving a problem of engineering origin by managerial methods through a stepwise approach.

Firstly the observational evidence was tested statistically. Difference of Means Test and Dixon's Test were used and it was shown that per unit cost shift was quite severe. To detect the main reason, seven major desulphurisation cost increasing reasons were quantified on monthly basis.

With the aid of forward selection method by stepwise regression procedure, the main reason was determined as the shift of the stone coal cost in 2005.

By the examination of 2004 and 2005 purchase data of stone coal, the cost components analysis had shown the cause. The gain of 0.53 US$/ton liquid hot metal due to the relative cheapness of American coal was reduced by 1.79 US$/ton cost increase in desulphurisation. Therefore the strategy to buy the American stone coal for the reason of its low price was wrong due to the high sulphur content of that sort of stone coal.

ÖZ

ENTEGRE DEMİR ÇELİK TESİSLERİNDE
KÜKÜRT GİDERME MALİYET DEĞİŞİMİ:
SAYISAL BİR ANALİZ

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Yüksek Lisans, İşletme
Tez Yöneticisi : Prof. Dr. Hasan Işın Dener

Eylül 2006, 62 sayfa

Kükürt giderme, demir çelik üretim sürecinde önemli bir aşamadır ve toplam üretim maliyeti içerisinde önemli bir yer tutar. İsdemir'de, 2004 yılına göre 2005 yılı aylık kükürt giderme maliyetlerinde önemli bir artış gözlendi. Bu konu, mühendislik kökenli bir problemin işletmecilikte kullanılan yöntemler uygulanarak adım adım çözümüne iyi bir örnek oluşturmaktadır.

Öncelikle gözlemsel kanıtlar istatistiksel olarak test edildi. Ortalamalar Farkı Testi ve Dixon Testi kullanıldı, ve birim maliyet artışının çok ciddi olduğu kanıtlandı. Temel nedenin belirlenmesi amacıyla, yedi önemli kükürt giderme maliyet artışı nedeni aylık olarak incelendi. Adım adım regresyon prosedürü bağlamında İleri Doğru Seçim Yöntemi yardımıyla temel neden, 2005 yılında taş kömürü maliyetinin değişimi olarak belirlendi.

2004 ve 2005 yıllarında satın alınan taş kömürü verilerinin maliyet bileşenlerinin incelenmesiyle gerçek nedenin Amerikan taş kömürünün kullanılması olduğu belirlendi. Amerikan taş kömürünün göreceli ucuzluğu nedeniyle sıvı ham demirin tonu başına kazanılan 0.53 doların, kükürt gidermedeki ton başına 1.79 dolarlık maliyet artışı nedeniyle zarara dönüştüğü bulundu. Bu nedenle, düşük fiyatı nedeni ile Amerikan taş kömüründen daha fazla satınalma stratejisi, bu kömürün yüksek kükürt içermesinden dolayı yanlıştır.

Anahtar Kelimeler : Kükürt Giderme, Taş Kömürü , Kükürt Giderme Maliyeti , İleriye Doğru Seçim Yöntemi

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER I

INTRODUCTION

1.1 Managerial Observations on Engineering Applications

Through the steady development of communication and transportation technologies, all goods and services are getting easily obtainable at every corner of the world. Increased competition in the world markets forces firms to deal with a greater number of competitors. As a result, firms share from the world markets diminish, so too their profits.

Under these conditions managers try to be more sensitive, careful and profound in dealing with a greater diversity of firm issues, with the hope that they could somehow contribute to steadily evolving and everlasting problems. They deal with engineering applications more than ever. For example, they are trying to observe engineering applications according to managerial standpoints, the type of optimisation understanding of business management, management principles and similar (usually somewhat systematised) collections of business management thoughts and ideas. Surely, their general aims do hardly change in essence, they search after decreasing the cost of production, increasing the sales, and conclusively increasing the profit of the firm.

The engineering subject matter of the present thesis resembles the outlook of a manager, in that it seeks reason why the problem occurs, and how it may be prevented from a manager's point of view.

1.2 The Subject Matter

The present study is devoted to set the solution to a real cost of production problem of a very large iron and steel plant through a step-by-step investigation of the cause .The firm is İskenderun Demir-Çelik Fabrikaları A. Ş., of which the well known abbreviated form of the name, "İsdemir" will be used throughout the present text.

The story of getting in touch with the possible cost problem by means of initial observations is simply as follows! İsdemir is producing primarily high quality steel out of liquid hot metal, and liquid hot metal is produced by using intermediate products, which come out of iron ore and stone coke. However, to get the liquid hot metal of acceptable quality, it must be purified by desulphurisation process. At the end, sulphur content will be decreased so much as to get the qualified steel, which will at the same time be produced during the desulphurisation process.

On the other hand, desulphurisation cost at İsdemir increased abruptly between 2004 and 2005. It was nearly 1.5 US$/ton in 2004, and had increased to about 4.4 US$/ton in 2005. The reasons of this drastic cost increase will be investigated in this study.

For that, the factors that affect the desulphurisation process will be examined in order to isolate the main reason by employing appropriate statistical techniques. The conclusion will then reveal the simple strategy of action to draw back the desulphurisation cost to its 2004 level.

In the coming chapter, after a brief account on İsdemir (as a company and as a production site), the explanation of the iron and steel production process, which would necessitate the desulphurisation process, will be forwarded. Details with no management relevance in this context, but might

still be of importance are kept in the Appendix. The engineering applications will also be considered as cost generating activities.

In the third chapter, desulphurisation process will be explained in further detail. Again the cost relevance will be shown and discussed. The inspected cost shift will be indicated with supportive data. Whether the observation concerning the drastic change of cost levels among 2004 and 2005 is true, will furthermore be verified by statistical tests.

Fourth chapter is devoted to the segregation of the main cause of desulphurisation cost shift of İsdemir between 2004 and 2005. Tests of elimination will be applied, and the result will be examined on logical grounds in conjunction with the peculiarities of liquid hot metal and desulphurisation processes.

Fifth chapter will investigate the most important reason of desulphurisation cost change and indicate its extent, variants, and cost saving possibilities. The last chapter will summarize the research attempt on the whole and put forward appropriate suggestions depending upon analytical findings of the previous chapters.

CHAPTER II

BLAST FURNACE PRODUCTION AT "İSDEMİR"

2.1 İsdemir

2.1.1 Introductory Descriptions

In the introductory chapter it was pointed out that the research problem, which can be subsumed as the "drastic cost increase of the desulphurization process", was a factual situation in the İsdemir plant of iron and steel products. Hence, to start with, it would be appropriate to give some relevant information about İsdemir.

İsdemir is the biggest integrated iron and steel plant in terms of the production capacity of long products. It was founded in 1970 at the Payas region, which lies 17 km to the north of İskenderun, and the site has an area of 6.8 billions of m^2. İsdemir plant includes units of coke, sinter, high blast furnace steel making, continuous casting and hot rolling.

At present, İsdemir has a long product total production capacity of 2.2 billions of tons/year. Existing production of İsdemir amounts to ca. 14 % of raw steel produced in Turkey. With such a high production capacity, İsdemir does not only satisfy the domestic demand, but also the international demand, whereby the exports are mainly directed towards the Middle East countries and the European Market.

In 2002 the Privatisation Administration transferred İsdemir shares to Erdemir Group. Afterwards, the shares of Erdemir were transferred to Ataer Holding. In 2006, all of the shares were owned by Oyak. The paid capital of İsdemir is at present 750 billion YTL (www.isdemir.com).

2.1.2 General Information about the Main Products of İsdemir

2.1.2.1 The Products

İsdemir was founded with the aim of producing long products such as billets, construction steel, wire rod. İsdemir also produces by-products of crude benzene, ammonium sulphate, coal tar and slag along with the above referenced main products. Moreover, İsdemir is selling raw iron ingot to iron casting factories.

İsdemir has signed agreements to produce flat products as well, and project studies have already been started in this respect (www.isdemir.com). Slab will be produced at Isdemir at the end of 2006, and coil will be produced from slab at İsdemir from 2008 onwards. Out of slab and coil of different qualifications carbon steels without alloy, cold rolled steels, hot rolled steels (which is appropriate for cold shaping), pipe steels, ship and tank steels, boiler steels, heat treatment steels with low alloy, HSLA steel sorts will be produced.

2.1.2.2 The Transportation of Raw Materials, Intermediate and Final Products

All of the coal and some part of iron ore or pellet are transported to İsdemir by sea. The seaway is also preferred for products, which will be exported. İsdemir has the deepest and the only jetty protected port of Eastern Mediterranean, and it has 12 billions of tons of loading and unloading capacity per annum (www.isdemir.com).

İsdemir is providing loading and discharging services of dry or other bulk cargo as stone coal, iron ore, pellet and general cargo (as billet) or construction steel during any time throughout a day. Within İsdemir plant, liquid hot metal and liquid steel is being transported from one unit of factories to others by railway. Heavy transporters or trucks are being used to transport the products of billet and coil from continuous casting or hot rolling factory units to the port. On the other hand, coal, iron ore, pellet, coke are transported from one factory unit to others by means of conveyor bands.

2.1.3 A Short Description of Production Processes at İsdemir for Liquid Hot Metal Production at High Blast Furnace

İsdemir is an integrated iron and steel factory, and therefore the production of steel is realised from liquid hot metal of own production. Liquid hot metal is the main intermediate product of steel, and it is produced at high blast furnace.

On the other hand, most of the steel factories in Turkey are of type Electrical Arc Furnace Steel Factory, and hence their production capacities

are relatively low in comparison with the integrated iron and steel factory at İsdemir. In these factories, steel will be produced from scrap directly in the electrical arc furnace, and therefore liquid hot metal will not exist as an intermediate product. Production flow at integrated iron and steel plant as İsdemir will pictorially be characterised in Figure1.
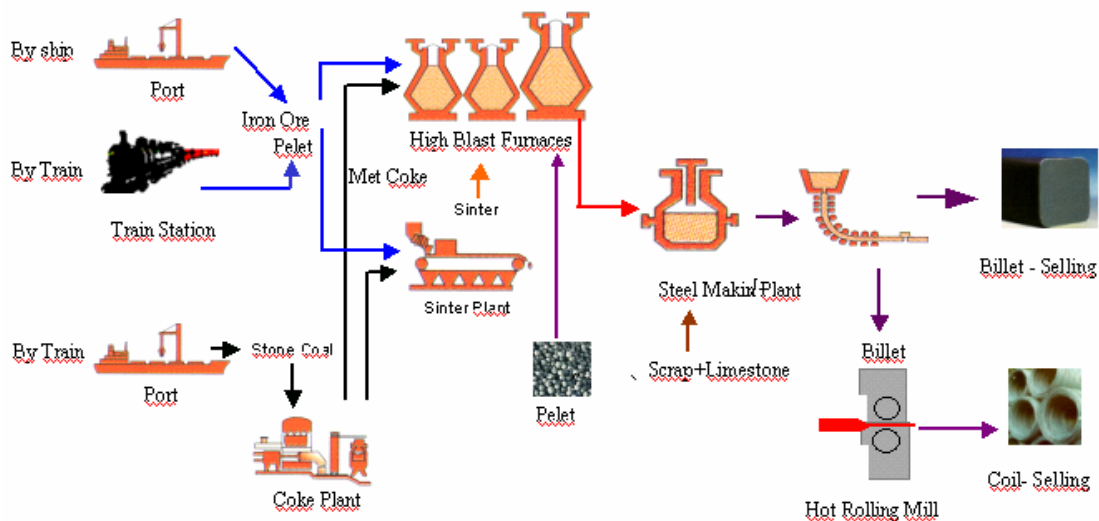
Figure 1: Production flow at integrated iron and steel plant (İsdemir, 2005)

İsdemir has its own port, with a total (loading and unloading) capacity of 12 Bil. tons . Iron ore or pellet is to be transported to İsdemir by means of train or ship, and they are stocked at some raw material stockpiling and preparing area, which belonged to sinter. Iron ore, coal (being brought from coal warehousing and preparation area), recycled ferric and ferrous products, and various fluxes are broken, and screened at required sizes.

Afterwards, a mixture of these materials is converted into agglomerate, with a specific chemical composition and size distribution that will be optimal for high blast furnace operation. The outcome will be the new intermediate product that includes iron, which is called "sinter". There is another material, being called "pellet", which is also kept at the raw material warehousing and preparing area. It includes again high amount of iron ore, and is used as

another intermediate product (such as sinter). However, pellet is used in smaller amounts than sinter.

When pellet is bought from domestic market, it is brought to İsdemir by train, and when it is imported from the foreign market, the transportation will be realised by sea. These two intermediate products are furthermore to be transported from sinter factory unit to high blast furnace by using the conveyor band.

Moreover some sorts of stone coal are required, which are usually imported from foreign market by sea. They will then be loaded into the stone coal warehousing and preparation area. The appropriate mixture of different coal sorts with required size is prepared there. Then it is brought to coke factory unit by means of the conveyor band. Metallurgical coke is produced from this coal mixture at coke factory unit. This is achieved by heating the coal up to $1250^{\circ}C$ in an oxygen-free atmosphere. Coke consists of more than 90 % carbon to serve as an energy supplier and chemical reagent at high blast furnace .

High blast furnace produces liquid hot metal by using sinter, pellet and coke in reducing the atmosphere. Before liquid hot metal is transported to steel making plant by railway, sulphur ratio in the liquid hot metal is decreased to the required level at desulphurisation factory unit.

Desulphurisation factory unit is physically separated from high blast furnace. Note however that, it is shown as if it belongs to high blast furnace within the realm of İsdemir organisational structure. Desulphurisation factory unit is located in between high blast furnace and steel making factory units.

After finishing the desulphurisation process, liquid hot metal is sent to steel making factory unit. At first, a few amount of scrap is added into liquid hot metal, and then liquid hot metal is converted into steel at the Basic Oxygen Furnace -through blowing pure oxygen with supersonic speed.

Finally, steel is sent to continuous casting factory unit. There steel is to be casted as billet of different sizes. According to orders, some part of billet is kept to be sold to domestic or foreign markets and some part of billet are sent to hot rolling factory unit. In the mentioned unit it is transformed into coil , which will again be sold in domestic or foreign markets. Coil and billet are thus the final products (Talay, 1977).

The above stated short description is adequate for the introductory information needs of the coming cost considerations. However, here and there, it might require more engineering information in order to be fully understood. For that reason, an "Appendix" is going to be adduced to the present text, where a thorough information about the mentioned blast furnace operations will furthermore be presented.

2.1.4 Importance of Liquid Hot Metal Production Among the Totality of Diverse Production Efforts at İsdemir

As it was mentioned above, liquid hot metal is produced at high blast furnace from coke, sinter, pellet, and the sulphur percentage in the liquid hot metal will be decreased at desulphurisation factory unit.

Decreasing sulphur at high blast furnace causes however certain and crucial increases in the levels of other detrimental elements, and consequently the production cost of liquid hot metal. About these, some introductory arguments will be presented in the coming subsection.

Although it seems that there are two main products (being billet and coil), it should be borne in mind that these two products can generate a lot of different products according to diverse chemical and physical compositions of

liquid hot metal. For example certain specified sulphur, carbon, silicon, phosphorus, etc. percentage rates form the basis for a specific product, and there might be lots of other percentage rate mixtures, which, at each time define other products. Hence for each of these different products, sulphur percent should again be adjusted at desulphurisation factory unit. In this sense, sulphur is one of the most detrimental element to be quantitatively adjusted at liquid hot metal phase, of which its decrease would tend to increase the production quality.

2.2 Cost Relevant Summary Description of Blast Furnace Operations Creating Sulphur-Based Waste Product

2.2.1 Introduction

Since the process that was spoken about is complicated enough, it would be appropriate at this point -before advancing any further in the next chapter- to have a summary. It will again be an engineering description, but emphasis will be paid to parts of the process, which would directly influence the variable cost.

At the same time, an overall insight of the totality of the process might be gained, which we will consider as the basic engineering knowledge of further elaborations on cost changes.

2.2.2 On the Process and Resulting Product by Means of High Blast Furnace Applications

As it was mentioned in the above Section 2.1.3; coke, which is produced at coke factory unit, sinter, which is produced at sinter factory unit, and pellet are all charged into high blast furnace.

In addition to these intermediate products, flux is used at high blast furnace to form slag. Flux can be pure high calcium limestone, dolomite limestone or a mixture of both. Flux is produced at limestone factory unit, and transported to high blast furnace by conveyor band.

The sinter and pellet are reduced by chemical reactions inside the high blast furnace, and oxygen is removed from iron. While the chemical reactions are happening, these materials begin to soften and melt, and finally liquid iron will trickle through the coke to the bottom of the furnace.

When the coke descends to the bottom of the furnace where the preheated air is blowed, it will be ignited to generate a very high temperature. At this high temperature carbon dioxide is transformed to carbon monoxide, and carbon monoxide reduces the iron ore (www.steel.org). Detailed information about this transformation can be obtained from the Appendix.

2.2.3 On the Simultaneous Slag Formation and Sulphur Sources in the High Blast Furnace

As it was mentioned in the introductory chapter, desulphurisation cost is our main concern. Below is the summary of that part of the story, by again emphasising cost creating processes

Oxides in the iron ore and additional material melt and combine, and then they are accumulated on the surface of liquid hot metal to form slag with the aid of density differentials at high blast furnace and desulphurisation factory unit. The oxides that formed slag are Al_2O_3 , SiO_2 , CaO , MgO , FeO , MnO and other sulphur compounds of minor importance. Therefore, sulphur is removed from liquid hot metal by slag.

Flux is used to provide this, as it was told at Section 2.2.1. Quality of hot liquid iron and features of the slag alter in connection with the regularity of work of the high blast furnace. In this sense, the most important features of slag formation are fusion, melting temperature, viscosity and the capacity of collecting sulphur. Different materials can be mixed with flux to form desired slag chemical content (Özgen , et. al. , 1991).

By İsdemir technology, it is required that slag should include high amounts of alkaline at high blast furnace. It also includes high amount of sulphur at the entrance of desulphurisation factory unit. Therefore, it is given due importance to remove alkaline from liquid hot metal at high blast furnace, in order to ease the removal of sulphur at desulphurisation factory unit.

Coke is the intermediate product in the production of liquid hot metal, which includes high amounts of sulphur. Sinter and pellet are other important intermediate products, which include high amounts of alkaline, and alkaline in turn effects sulphur level deliberately. Coke ash also contains high amounts of sulphur and it is loaded to high blast furnace, unfortunately together with coke.

Conclusively, the main two sources of sulphur are stone coal for coke and iron ore for sinter or pellet.

2.3 Further Approach

In the coming chapter, the desulphurisation process will be reconsidered, this time as a data creating industrial activity source -by relating the engineering facts with managerial and economic aims.

Therefrom the applicable İsdemir data -consisting of monthly time-series- will operationally be defined, and forwarded in order to provide some basic statistics, out of which evidence for the observed unit cost shift of desulphurisation will be tried to be detected statistically.

Therefore, the main task of the latter part of Chapter III will be to test the formulated hypothesis, in order to conclude on whether the crude observation concerning the mentioned cost change will statistically be justifiable or not.

CHAPTER III

DESULPHURISATION PROCESS IN THE PRODUCTION OF LIQUID HOT METAL, AND ITS DATA AS EVIDENCE FOR DRASTIC UNIT COST CHANGE

3.1 Need for Desulphurisation Process for Liquid Hot Metal

Sulphur is present in solid steel as manganese sulfide (MnS) inclusions. Their volume fraction, size, shape and distribution depend on the sulphur content, oxygen content, and furthermore the solidification rate, degree of hot and cold deformation, and hot working temperatures.

These MnS inclusions have several effects on the processing and properties of produced steel. We should take care of the fact that mainly these effects are detrimental, since the mentioned inclusions are more plastic than steel and, hence, during deformation of the metal, they might act as crack initiation sites and zones of weakness.

Sulphur is detrimental to ductility, toughness, formability, weldability and corrosion, resistance. Sulphur is only somewhat suitable for machinability. Therefore, it is evident that it must be removed.

Sufficient manganese must be present in the steel to prevent the formation of iron sulfide, which itself, as a compound, is highly detrimental to hot workability, and leads to severe cracking during hot rolling (hot shortness).

The most demanding applications of steel require the sulphur quantity to reduce to very low levels (<0.001% S), in order to achieve the required

combination of strength, ductility, formability and weldability (www. steeluniversity.org). For applications, which are extensively machined during manufacturing, somewhat higher levels of sulphur might be required, but such are rather for specific use only.

3.2 The Control Possibility of Sulphur at Blast-Furnace

Iron ore used at İsdemir is provided from domestic sources by 70 - 80 % of the total. Domestic iron ore is used at production of sinter extensively, since it increases the alkaline (K_2O+ Na_2O) amount of liquid hot metal in the high blast furnace by 60-70 %.

Alkaline is another detrimental material like sulphur, and its proportion must also be decreased. However, decreasing alkaline and sulphur amounts simultaneously at the high blast furnace requires opposite precautions to be taken. Decreasing alkaline amount at high blast furnace requires working with acid slag, but exactly this way of approach increases the amount of sulphur at high blast furnace (Uçar, Eralp , 2001).

Moreover, decreasing the sulphur amount at high blast furnace requires an increase in the volume of slag and its basicity. To realise it, amount of coke used at blast furnace should be increased, but this leads to an unproductive way of manufacturing, and it is surely not economic. Therefore the operation of decreasing amount of sulphur in the liquid hot metal (which is nothing but what we call "desulphurisation process") is needed to be made in some facilitated manner, ie. at the separate desulphurisation factory unit and not within the high blast furnace.

3.3 Desulphurisation

3.3.1 Summary Description of Work at Desulphurisation
     Factory Unit

Desulphurisation plant is constructed out of a single unit of 5.2 m^3 main granule magnesium tank with 6 atm N_2 pressure, two units of 2 m^3 granule magnesium tank, one unit of crane with a carrying capacity of 5 tons, 9 atm pressure N_2 and O_2 gas systems and two units of lance for blowing (Uçar, Eralp , 2001).

The process will be summarised below. In case that the desulphurisation plant might not be visualised readily, its flow sheet is given below on Figure 2:
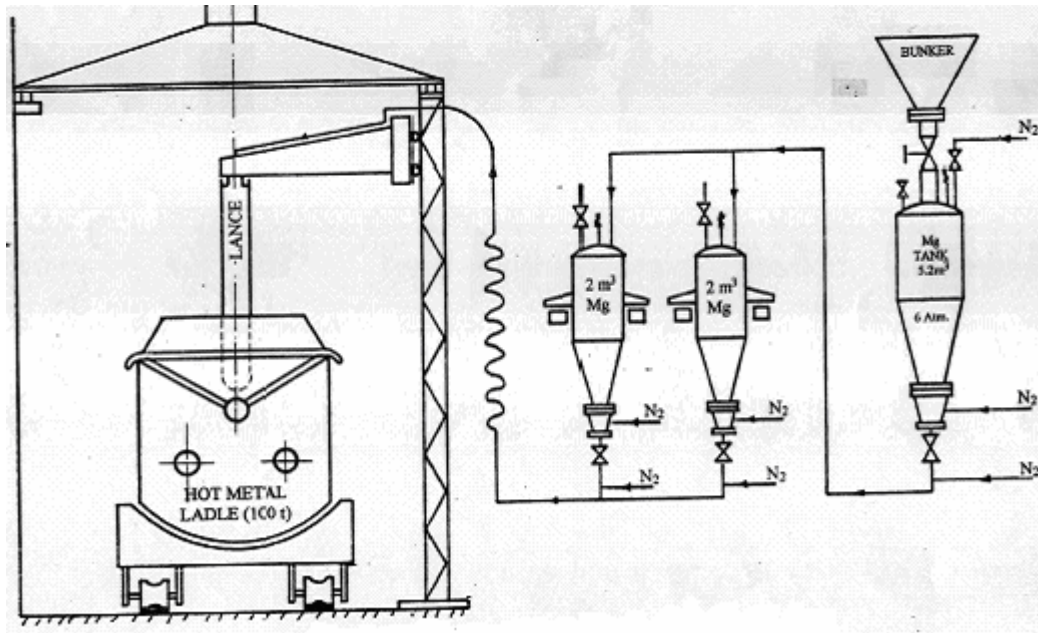
Figure 2: Desulphurisation plant flow sheet (Talay ,1977)

During the desulphurisation process, granule magnesium will be blown into liquid hot metal at supersonic speed together with nitrogen and oxygen gases. Nitrogen is used to prevent lance to be plugged. Sulphur is removed by slag-liquid metal reactions under reducing conditions, in which the sulphur itself is to be transferred from the steel through the slag-metal interface and into the slag. The basic chemical reaction in desulphurisation is therefore,

$$FeS + MgO + C = MgS + FeO + CO \qquad (1)$$

Upon finishing this reaction, the slag, which includes high amounts of sulphur compounds, will be accumulated on the surface of liquid hot metal. Afterwards, slag can be taken from the surface of liquid hot metal before it will be poured into the mixer (Özgen , et. al. , 1991).

3.3.2 Determinants Affecting Desulphurisation Costs

There are two main factors that would constitute the variable cost of desulphurisation process. They are the cost of magnesium amount, which is the main desulphurisation material, and the cost of number of lance which is used for blowing magnesium inside the liquid hot metal.

The costs are more or less proportional to how much desulphurisation is made. Other cost factors can be accepted as fixed costs, since they don't change much with the intensity of the process. Out of them, especially workers' payments and other labour cost can readily be accepted as fixed cost, since number of workers per shift doesn't change according to the production amount, and desulphurisation factory unit is working 24 hours in a day during all the year. Nevertheless, if we examine what was achieved, we

observe that the production amount did not change so much between 2004 and 2005, 2004 and 2005 being the time points of comparison.

3.3.3 Some Conclusions by Viewing the Values of Indicator Variables of Determinant Factors

When we look at the average sulphur percentage of liquid hot metal which was produced at high blast furnace, we conclude that in İsdemir 0,0323 % increase at average sulphur ratio between 2004 and 2005 was registered, - a calculation stemming from the data of Table 1 below. In Table 1, the monthly average sulphur ratio of liquid hot metal is given.

It is noteworthy that from here onwards real data of isdemir will be used. They are taken from "Kalite ve Metalürji Müdürlüğü" of İsdemir. Within the realm of İsdemir 's local area network, they can also be easily accessed.

Table1: Monthly Average Sulphur Percentage of Liquid Hot Metal That Was
Produced at High Blast Furnace: 2004, 2005.

Months	At High Blast Furnace 2 in 2004	At High Blast Furnace 3 in 2004	At High Blast Furnace 2 in 2005	At High Blast Furnace 3 in 2005	Average in 2004	Average in 2005
January	0.0587	0.0773	0.0962	0.0991	0.0696	0.0979
February	0.0699	0.0834	0.0957	0.0941	0.0779	0.0947
March	0.0583	0.0799	0.1030	0.1082	0.0710	0.1060
April	0.0757	0.0711	0.1005	0.1277	0.0730	0.1165
May	0.0588	0.0741	0.1130	0.1395	0.0678	0.1286
June	0.0712	0.0769	0.1127	0.1166	0.0746	0.1150
July	0.0833	0.0768	0.1196	0.1124	0.0795	0.1154
August	0.0887	0.0957	0.1296	0.1158	0.0928	0.1215
September	0.1029	0.1010	0.1353	0.1278	0.1018	0.1309
October	0.0899	0.0924	0.1270	0.1170	0.0914	0.1211
November	0.0940	0.0991	0.1250	0.1080	0.0970	0.1150
December	0.0832	0.0889	0.1130	0.1040	0.0865	0.1077
Average	**0.0779**	**0.0847**	**0.1142**	**0.1142**	**0.0819**	**0.1142**

The conclusion stemming from the data values is straightforward! Desulphurisation process seemed to be more activated in 2005, in order to remove this serious increase of sulphur ratio. In 2005 the cost of desulphurisation process increased seriously too, since the desulphurisation process to be fulfilled required a greater use of magnesium and lance.

On the other hand, sulphur ratio of liquid hot metal which was processed at desulphurisation factory unit in 2005 decreased with respect to 2004 by 0.0179 %. The monthly average sulphur percentage of liquid hot metal, which was processed in the desulphurisation plant is given Table 2.

Throughout the process, since its goal is to increase the steel quality, when extra amounts of magnesium and lance are used, the cost of desulphurisation process should further be increased. However, the choice is at the common discretion of chief engineers and managers, and will also be influenced by the metal properties expected by potential customers from their orders. Therefore, this respect of cost increase is not accountable on rational grounds, and won't be taken into consideration in the realm of the present study.

Table 2: Monthly Average Sulphur Percentage of Liquid Hot Metal Which was Processed at Desulphurisation Plant: 2004, 2005.

Months	After Desulphurisation in 2004	After Desulphurisation in 2005
January	0.0466	0.0388
February	0.0494	0.0298
March	0.0486	0.0274
April	0.0527	0.0251
May	0.0489	0.0230
June	0.0469	0.0296
July	0.0463	0.0349
August	0.0527	0.0333
September	0.0519	0.0313
October	0.0535	0.0304
November	0.0483	0.0266
December	0.0418	0.0421
Average	**0.0490**	**0.0310**

3.4 Detection of the Desulphurisation Cost Shift Problem out of Data Sets

3.4.1 Selected Monthly Data of the Desulphurisation Factory Unit

Since the desulphurisation factory unit works in dependence with high blast furnace (according to the organisational structure of İsdemir), cost of desulphurisation process takes part in the cost report of high blast furnace.

Monthly average sulphur ratio of liquid hot metal, which was produced at high blast furnace and processed at desulphurisation factory unit, had already been given on Tables 1 and 2. The monthly cost of the desulphurisation process and the monthly production amount of liquid hot metal in 2004 and 2005 will be shown at Table 3 below.

On this occasion, note that the reason why the short run data is given at monthly basis has no other rationale than "availability". Since cost reports are prepared monthly, there was no other possibility than using the data on monthly basis. However, the unit time span is found out to be adequately suitable in detail, so that what we here subject to examination by means of constructing statistical hypotheses –as they will be seen below- can without doubt be accepted or refuted according to the monthly unit of measurement.

3.4.2 Observational Evidence for Drastic Cost per Unit Shift between 2004 and 2005

We can easily observe from data of the Table 3, that desulphurisation cost increases averagely from 1.5 US$/ton in 2004 to 4.4 US$/ton in 2005. Thus, the increase is nearly 3 US$/ton. It seems to be huge.

However, mere observation might be misleading. It doesn't indicate whether that jump is statistically significant (important) or not, given the statistical distributions out of which those amazing, drastic changes are registered.

Table 3: Monthly Average Cost of Desulphurisation Process, and Monthly Liquid Hot Metal Production Amount: 2004, 2005

Years	Months	The Cost of Desulphurisation Process (usd / ton L H M)	The Amount of L H M (ton)
2004	January	0.78	202,200
	February	0.98	185,796
	March	1	195,762
	April	1.42	158,644
	May	0.96	187,281
	June	1.4	198,542
	July	1.55	188,639
	August	1.8	189,771
	September	2.35	179,249
	October	1.77	176,155
	November	2.35	182,085
	December	2.09	204,702
	Average	1.538	187,402
2005	January	3.44	188,724
	February	3.21	171,756
	March	4.96	172,790
	April	5.05	184,932
	May	4.6	190,016
	June	5.18	175,396
	July	3.49	183,078
	August	6.13	184,248
	September	4.64	185,196
	October	3.93	195,648
	November	4.33	191,601
	December	3.86	199,428
	Average	4.402	185,234

3.4.3 Statistical Evidence of High Shift by Average Cost

3.4.3.1 Examining the Difference of 2004 and 2005 Average Unit Costs of Desulphurisation by Difference of Means Test

"Yearly average cost per ton", which was used in the previous section as the unit of measurement, is nothing but the arithmetic mean of the monthly "cost per ton" figures for 2004 and 2005. Therefore, an appropriate statistical tool, in order to detect whether the sharp change of "cost per ton" in between 2004 and 2005 is statistically significant or not, is "the difference of means test". The test will examine, whether the observed remoteness of yearly "cost per ton" arithmetic means had been significantly distant from each other or not.

If $\bar{x}_{05}$ is the yearly average cost per ton of 2005, and $\bar{x}_{04}$ that of 2004, whereby s^2_{05} and s^2_{04} are the respective variances (being calculated out of monthly data of the consecutive years), and in case of unknown population variances, the test parameter is "empirical t". Since at this special situation, the degrees of freedom of samples of 2004 and 2005 are both 12, the formula of the "empirical t" will reduce to

$$t = \frac{\left| \bar{x}_{0.5} - \bar{x}_{0.4} \right|}{\sqrt{\dfrac{s^2_{05} + s^2_{04}}{n}}} \tag{2}$$

where n is nothing but 12.

t out of (2) should then be compared with the respective table value of the t-distribution. In this case of unknown population variance, the degrees of

freedom (d.f. in abbreviation) would better be calculated by the more exact Behrens-Fisher formula. However, since n is common, it will be reduced to

$$\text{d.f.} = \frac{s_{05}^2 + s_{04}^2}{s_{05}^4 + s_{04}^4}.(n-1) \quad , \quad \text{(Dener, 2000)} \tag{3}$$

In using the t-table, we should decide on the confidence level. To set the confidence level is a matter of choice of the researcher. However here, we even don't need to specify it due to the "relative high value" obtained for the "empirical t".

"Empirical t" is found out to be 9.7. Since even at 99.9 % significance level "theoretical t" is about 3.8, the result seems to be "very highly significant". In statistical sense it means that the 2004 and 2005 unit cost figures stem from different populations. Hence their diversion from each other is not accidental. Therefore, in the year 2005 with respect to that of the year 2004 there exists a severe cost problem created by desulphurisation process in İsdemir, of which the principal causes should be found out.

3.4.3.2 Strengthening the Conclusion by Dixon's Outlier Test

If we blend together the desulphurisation process cost data of 2004 and 2005, and get a 24 months' data set, the mixed distribution gives the impression that the data of 2004 and 2005 are of different nature. It is even so that, the minimum value of 2005-distribution is greater than the maximum value of 2004 distribution.

This situation reminds a possibility, to strengthen the validity of the conclusion arising from the "difference of means" test. To the maximum of

2004 monthly value together with the minimum of 2005 monthly value we might apply Dixon's outlier test.

In statistical sense, an "outlier" is some too great or too small a value within the data of a distribution and it doesn't seem to belong to that distribution. Therefore, an outlier test shows (at a specific level of confidence) on whether that datum is probably not belonging to the distribution, in which it is factually situated.

If the average cost distributions of 2005 and 2004 lie so apart, that even the minimum of 2005 distribution is greater than the maximum of 2004 distribution, we can straightforwardly accept this as a further affirmation of the result of the "difference of means test", which was conducted above. The attempt, which is planned now, would furthermore hypothesise that the 2005 monthly results are really very remote to those of 2004. If the hypothesis we are going to form below will be affirmed, it will additionally come out that the problem is more serious, and must at once be overcome.

Here, for our purpose, we shall employ Dixon's outlier test (Caulcutt ,1983).

Dixon's test is easy to grasp. First we order the n-data of a distribution from biggest to smallest, or from smallest to biggest. An outlier would lie at some end of this ordering. Let us call it X_1. Let again the last datum of the distribution, (ie. the smallest when we array the data from small to big, or the biggest when we order the data from big to small) be symbolised by X_n.

Dixon had calculated theoretical values for a table of significance, to show whether certain results owing to his formulas would indicate that X_1 is an outlier or not –surely at a desired level of significance.

In our case, the planned test would entail 12 monthly values for 2004 and the minimum value of 2005 data, to form a 13 valued distribution. By that distribution, we furthermore know that

$X_{min,05} > X_{max,04}$ (4)

So what will be tested is "whether $X_{min,05}$ is an outlier to the 2004 distribution or not" at a plausible level of significance. For n = 13, Dixon's formula in order to get the comparable test value with that of the table at same degrees of freedom will for 13 data be

$$Dix = \left| \frac{X_1 - X_3}{X_1 - X_{n-2}} \right|$$ (5)

By employing (5) if

Dix > (Corresponding table value) (6)

X_1 will be an outlier at the tabular level of significance (Dixon ,1950)

In our case, Dix appears to be as 0.39. It corresponds to about 80 % level of significance. The conclusion is remarkable. In case that the difference of means of 2004 and 2005 distributions is significant at 99.9 and more percent level, the minimum of the 2005 distribution seems furthermore to lie as an outlier with respect to the maximum of the 2004 distribution indicates a certainty for the cost jump under examination.

Actually, the application of Dixon's test in addition to the clear-cut result of the difference of means test was unnecessary. Here, it was carried out to prevent criticism concerning inflationist pressure.

We know that throughout the period under concern a monthly average increase of input prices was somewhat less than 1 % (as it will be indicated with the data to be presented in Chapter V). However, just theoretically speaking, if the cost generating input price increases were very high (as in the last decade of the 20th century), then the average costs of two consecutive years could also fall quite apart -due to another but (under the expectations for a real cost change) a deceptive cause. To refute the presence of such a cause strongly, the Dixon test was applied for the comparison of monthly data in (4).

CHAPTER IV

DETECTING THE MAIN CAUSE OF
DESULPHURISATION COST SHIFT

4.1 Indicators of Determinants Affecting Desulphurisation Cost Revisited

As it was told in Section 3.3.3 above, there seem to exist two main reasons for the mentioned drastic desulphurisation cost increase in 2005. First of them was caused by the increase of average sulphur ratio of liquid hot metal. -from 0.0819 in 2004 to 0.1142 in 2005. Therefore the task of removing this extra sulphur amount in the liquid hot metal in 2005 increased the cost of desulphurisation process.

Second reason is that the minimum sulphur level of liquid hot metal, which was processed at desulphurisation factory unit, decreased from 0.049 in 2004 to 0.031 in 2005. Therefore, in 2005 the process of desulphurisation had to be extended somehow. However, this was the choice of managers to produce more quality products.

Therefore, the first reason of 0.0323 % unexpected increase in the average sulphur ratio of liquid hot metal) will only be dwelt upon in this study.

4.2 Specifying Possible Causes of Cost Shift

The reason of the mentioned sulphur level increase in the liquid hot metal in 2005 should might been attributed to the changes in the use of intermediate products at high blast furnace between 2004 and 2005. To find which intermediate product has or which intermediate products have relatively greater effects on sulphur level increase in the liquid hot metal, all the principal factors were taken into account.

These factors are percent of slag basicity, value of coke/liquid hot metal (in terms of kg/ton), percent of sulphur in coke, percent of CaO in coke ash, percent of Al_2O_3 in sinter, percent of Al_2O_3 in slag, percent of Al_2O_3 in pellet. These 7 different data are given in Table 4 as average percentage values for the months of the years 2004 and 2005.

4.3 Specifying Significant Causes of Desulphurisation

4.3.1 Forward Selection Method to Identify Significant Causes

4.3.1.1 Introduction

Out of the 7 factors, of which the data are given in Table 4, the most significantly influencing factor or factors being responsible for the desulphurisation cost shift of 2005 should be isolated. This can be achieved by employing appropriate statistical methods.

The method being applied to the average costs and the data of Table 4 is "stepwise regression" in its version, which is called "forward selection" (Dodge, 2003). Below the method will briefly be described, and afterwards the results of the application will be shown step by step.

Table 4: Monthly Average Percentage Values of Factors that Affect Sulphur
Levels of   Liquid Hot Metal

Months	Y	X1	X2	X3	X4	X5	X6	X7
	% Sulphur in L H M	% Slag Basicity	Coke / L H M (kğ/ton)	% Sulphur in Coke	% CaO in Coke Ash	% Al$_2$O$_3$ in Sinter	% Al$_2$O$_3$ in Slag	% Al$_2$O$_3$ in Pellet
2004 Jan.	0.0696	0.8206	545	0.41	2.62	1.91	14.339	0.5803
2004 Feb.	0.0779	0.8741	504	0.56	2.85	1.74	14.096	0.2634
2004 Mar.	0.0710	0.8806	510	0.53	1.51	1.47	13.179	0.5753
2004 April	0.0730	0.8417	516	0.53	1.52	1.85	13.484	0.4115
2004 May.	0.0678	0.8724	520	0.69	2.48	1.73	12.694	0.4186
2004 June	0.0746	0.8559	502	0.66	2.57	1.84	13.832	0.4816
2004 July	0.0795	0.8635	500	0.63	3.52	1.77	11.852	0.5367
2004 Aug.	0.0928	0.8224	486	0.62	2.25	1.63	11.743	0.4136
2004 Sep.	0.1018	0.8376	504	0.65	2.86	1.57	10.799	0.3832
2004 Oct.	0.0914	0.8541	500	0.63	4.35	1.88	11.643	0.3300
2004 Nov.	0.0970	0.8559	498	0.68	2.79	1.92	11.622	0.3049
2004 Dec.	0.0865	0.8541	481	0.57	1.71	1.97	13.360	0.5428
2005 Jan.	0.0979	0.8559	492	0.61	0.56	2.18	13.876	0.5639
2005 Feb.	0.0947	0.8600	505	0.55	3.52	1.84	12.528	0.4234
2005 Mar.	0.1060	0.8465	514	0.66	3.66	1.59	11.873	0.3321
2005 April	0.1165	0.8206	513	0.66	3.15	1.88	12.757	0.6113
2005 May	0.1286	0.8048	511	0.68	3.64	1.98	14.481	0.5252
2005 June	0.1150	0.7641	517	0.67	2.89	1.74	13.568	0.4258
2005 July	0.1154	0.7800	527	0.68	2.92	1.74	12.988	0.4575
2005 Aug.	0.1215	0.7400	515	0.71	2.71	2.08	15.055	0.5400
2005 Sep.	0.1309	0.7300	521	0.69	2.66	2.08	14.682	0.8979
2005 Oct.	0.1211	0.7641	525	0.96	2.71	1.64	13.494	0.4223
2005 Nov.	0.1150	0.7959	516	0.63	2.90	1.64	12.663	0.1295
2005 Dec.	0.1077	0.8259	510	0.62	2.72	1.66	12.655	0.3996

4.3.1.2 Preliminaries for a Short Description of the Forward Selection Method

Suppose that there are m independent variables; $X_1, \ldots, X_m$, that would effect the dependent variable Y. The regression equation of linear dependence will be.

$$Y = C_o + C_1 X_1 + \ldots + C_m X_m \tag{7}$$

where C's are regression coefficients to be estimated.

To get the regression coefficients, (if the number of data is "n") the set of "m" normal equations can be symbolised as

$$\Sigma Y_j = n C_o + C_1 \Sigma X_{j1} + C_2 \Sigma X_{j2} + \ldots + C_m \Sigma X_{jm}$$

$$\Sigma Y_j X_{j1} = C_o \Sigma X_{j1} + C_1 \Sigma X_{j1}^2 + C_2 \Sigma X_{j2} X_{j1} + \ldots + C_m \Sigma X_{jm} X_{j1}$$

$$\Sigma Y_j X_{j2} = C_o \Sigma X_{j2} + C_1 \Sigma X_{j1} X_{j2} + C_2 \Sigma X_{j2}^2 + \ldots + C_m \Sigma X_{jm} X_{j2} \tag{8}$$

$$\Sigma Y_j X_{jm} = C_o \Sigma X_{jm} + C_1 \Sigma X_{j1} X_{jm} + C_2 \Sigma X_{j1} X_{jm} + \ldots + C_m \Sigma X_{jm}^2$$

Simultaneous solution would give $C_o, C_1, \ldots, C_m$

By replacing these constant values into (7), for each one-to-one related data set (like e.g. the January 2004 data of the 7 variables, the February 2004 data of the 7 variables etc.) we will get the corresponding Y-estimates. They will here be symbolised by $\hat{Y}_j$'s, where each j denotes a time point.

For all data from 1 to n,

$$Y_j - \hat{Y}_j = e_j \tag{9}$$

as being the deviations from the original data of the dependent variable, we will get regression errors.

Therefore, sum of regression error squares for all the multivariate data is

$$SSE = \Sigma (Y_j - \hat{Y}_j)2 \tag{10}$$

Hereby, the numerator of variance, being "total sum of squares" we might symbolise with

SST = Σ (Y$_j$ - Ỹ)^2 (11)

Hence, sum of squares explained by the regression will be

SSR = SS$_T$ - SS$_E$ (12)

SSR is showing how successful the regression model is in explaining the variation among independent variables and the dependent variable. (Hines, Montgomery, 1990)

4.3.1.3 Forward Selection Method

Forward Selection Method is based on adding variables to the regression model, which contribute most in every regression estimate. The greatest contribution will be understood through the application of F-test and partial F-tests, and their comparison. Adding variables to the model would continue until there won't remain any variable, which would provide a further significant increase at SSR. Surely, the level of significance will remain as the choice of the researcher.

To recollect, empirical F-ratio is known as

$$F = \frac{\dfrac{SSR}{m}}{\dfrac{SSE}{n-m-1}}$$ (13)

One might start with one independent variable form of the general linear regression model [7] and get C_0, C_1, and then C_0, C_2 etc. etc. for all two variable linear models. The independent variable, of which the data achieve the highest correlation with 'Y' would yield the largest F statistic.

For example, let it here be X_1.

At the next step, m-1 remaining independent variables will be inserted into alternative 3-variable linear regression models. The partial F-test, stemming from the definition in (13) would include, e.g. for X_i

$$F_{par.} = \frac{SSR(X_i\, given\, X_1) - SSR(X_1)}{\dfrac{SSE}{n-m-1}}$$ (14)

Note that in [14] the denominator degrees of freedom of the numerator of F in (13) will be nothing but 1, since we deal with the explanation of a single variable (exactly as it is also the case by the partial correlation coefficients).(Hines, Montgomery, 1990)

After computing all possible $F_{par.}$'s, of all independent variables X_i, if

Max $[F_{par.,All\ X\ without\ X1}] > F_{Tab.}$ (15)

at the desired level of significance, we can include the variable that generated the maximum partial F, and go on like that.

If [15] doesn't hold any more, we stop with the forward selection procedure, since we should have found our "most influencing" variables within the realm of the last model of the previous phase.

The "forward selection method", being applied to the 7 independent variables of Table 4 was implemented by using EXCEL In the next section the results of the mentioned application will be forwarded according to its step-by-step approach.

4.3.2 The Empirical Application of Forward Selection Method on the Indicator Variable Data

4.3.2.1 Statistical Approach

To start with, in the initial two-variable regression phase, the most important factor that affect the sulphur level of liquid hot metal was found out from the partial F's as shown in Table 5.

Table 5: Partial F's Stemming from the First Phase Application of Forward Selection Method and the Comparison with Significance Value

Variable	X_1	X_2	X_3	X_4	X_5	X_6	X_7
F:	36.962	0.649	12.306	2.198	0.879	0.675	0.537

Max $\{F_1, F_2, F_3, F_4, F_5, F_6, F_7\} > F_{0,05;\ 1,22} = 4,3$

Therefore in the first phase, variable X_1 will be selected.

Table 6 indicates the same type of results, which were computed for the second phase.

Table 6: Partial F's Stemming from the Second Phase Application of Forward Selection Method and the Comparison with Significance Value

Variables:	X_2	X_3	X_4	X_5	X_6	X_7
F:	3.6321	3.9466	2.6678	0.0097	2.7703	0.6374

Max $\{ F_{x2}, F_{X3}, F_{x4}, F_{x5}, F_{X6}, F_{x7}, \} > F_{0,05; 2,21} = 3,46$

Therefore in the second phase, X_3 will furthermore be selected.

The third phase results will finally be demonstrated in Table 7 below.

Table 7: Partial F's Stemming from the Third Phase Application of Forward Selection Method and the Comparison with Significance Value

Variables:	X_2	X_4	X_5	X_6	X_7
F:	2.47943	1.89416	0.28012	1.32191	1.28998

Max $\{ F_{x2}, F_{x4}, F_{x5}, F_{X6}, F_{x7}, \} < F_{0,05; 3,20} = 3,09$

Therefore in the third phase we stop, and cannot include any other variables since the corresponding table value becomes bigger than the maximum of the partial F's.

The regression model with selected variables of highest influence will then be estimated as

$Y = 0.311 - 0.3017 X_1 + 0.0569 X_3$ (16)

where X_1 denotes slag basicity and X_3 the sulphur level of the coke.

4.3.3 On the Detected Significant Causes

The above stated results indicate that Y, the level of sulphur in the liquid hot metal, depends primarily on basicity level of slag, and sulphur level of coke.

In (16) we observe that the regression coefficient of slag basicity is negative, which is in accordance with the expectations that when basicity level of slag is increased, sulphur level of liquid hot metal decreases. This should be kept in mind when reading the below stated controversy.

The coefficient of sulphur level of coke being positive reflects also the expectations, such that the sulphur level of coke directly effects sulphur level of liquid hot metal in direct proportion.

On the other hand, the same calculations reveal that sinter or pellet do not have as much effect as the above mentioned two variables.

4.4 Selecting Cost Sensitive Cause as Sulphur Content of Coke Used

It was also pointed out earlier that there is furthermore an alkaline percentage problem as well as that of sulphur at the high blast furnace, and it must be decreased too. But decreasing alkaline and sulphur amounts at the high blast furnace mutually, require opposite precautions.

It is required to work with acidic slag in order to decrease alkaline percent, and at the same time slag must be basic in order to decrease sulphur percent. At İsdemir, it is preferred to remove alkaline within the liquid hot metal at the high blast furnace, whereas sulphur amount will be decreased at desulphurisation factory unit. Therefore basicity of slag in the high blast furnace is kept at the low level, and it is acidic. Generally, this condition won't be changed often for purposes of decreasing the level of alkaline in the liquid hot metal.

Hence, out of the two important influencing factors, it is not necessary to take the basicity of slag into consideration. The regression equation [16]

indicates the truth in this assertion from mathematical viewpoint, and reflects the mentioned reality in estimates depending on real data, by letting the regression coefficient of slag basicity to appear as negative.

Therefore, only one influencing variable remains to be investigated as the source of drastic cost shift, and it is the sulphur level of coke.

CHAPTER V

EXAMINATION OF COKE COMPOSITION BY ORIGIN BEFORE AND AFTER THE DRASTIC COST SHIFTS IN THE PROCESS OF DESULPHURISATION

5.1 Detection Approach for the Main Cause of Cost Shift of Desulphurisation

As the result of "forward selection method" application, there remained 2 reasons, which seemed statistically important, among the possible causes for the 2005 cost shift of desulphurisation. One of them –the slag basicity- could not possibly be a cost reducing main source, for the logical reason that its reduction would increase the cost of desulphurisation directly. Thus there remained only a single cause, being the sulphur percentage increase in the liquid hot metal, upon which we shall dwell in this chapter.

Sulphur percentage increase in the liquid hot metal depends upon the increase in the sulphur percentage content of the coke used. On the other hand, the coke coal being produced at İsdemir was extracted from a mixture of different stone coals, which was mainly imported from different countries.

Therefore, we should investigate the features of coke and different stone coals, and examine the cost affecting quantitative changes in the use of these stone coals among the years 2004 and 2005.

5.2 Features of Coal Used by İsdemir

5.2.1 Before the Cost Shift: In 2004

It should have been understood that the source of sulphur in the liquid hot metal is coke. Main properties of coke, which was produced in 2004 at coke factory unit is given in the Table 8.

Table 8: The Features of Coke in 2004

	Moisture %	Ash %	Volatile	Sulphur %	Kcal/kğ	Stability %	Hardness %
2004 Average	0.366	11.58	0.938	0.598	6672.75	55.576	65.258

It is to observe that average sulphur of coke in 2004 is 0.598 %, and this coke coal was produced from the stone coals which were imported from five countries. The features of these stone coals are stated in Table 9 according to the country of origin.

Table 9: The Features of Stone Coals Used in 2004

	Origin	Moisture %	Ash %	Sulphur %	Phosphorus %	Kcal/kğ	Stability %	Hardness %
2004 Average	USA	7.684	9.2	0.919	0.013	6969.4	50.5	63.4
	Turkey	7.642	11.6	0.588	0.022	6783.5	41.1	58.1
	Canada	8.720	8.9	0.553	0.053	6901.2	58.9	65.6
	Ukraine	9.305	8.6	0.634	0.008	6797.8	56.7	64.0
	Poland	9.950	8.6	0.554	0.022	6885.5	59.0	64.3

It is seen from the table that sulphur percentage of stone coals changes between 0.919 % and 0.553 %. Sulphur content of the stone coal imported from USA is higher then other coal intake. The amount of each stone coal, which is used to produce coke must separately be taken into consideration, since each of them effect the sulphur percentage of coke and consequently their prices effect the cost of desulphurisation process. Table 10 and Figure 3 indicate the amounts of stone coals used and the average unit price of each of them in 2004.

Table 10: Quantities Purchased and Prices of Stone Coals in 2004

Country	Amount of coal (tone)	Percent of coal (tone)	S %	Price (USD/tone)
U.S.A.	905,498.3	0.510	0.92	$95
Turkey	35,746.5	0.020	0.58	$120
Canada	564,538.1	0.318	0.55	$116
Ukraine	222,679.4	0.126	0.63	$127
Poland	45,300.6	0.026	0.55	$133
Total	1,773,762.8	1.000		
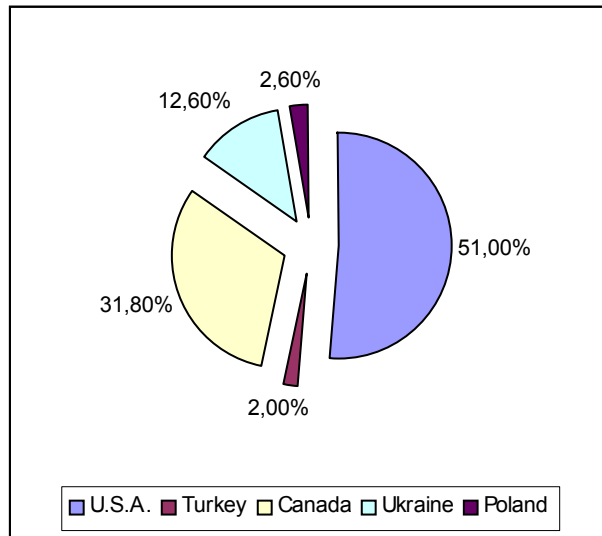
Figure 3: Percent of Stone Coals Used in 2004 According to Origin

As will readily be seen, total amount of stone coals used in 2004 was 1.773.762 tons, and stone coal imported from USA was higher than the others. The prices of coal had ranged between 95 US$ and 133 US$

5.2.2 After the Cost Shift: In 2005

In the same manner as they were illustrated in Tables 8, 9, 10 and Figure 3 for the year 2004, the tables and the figure for 2005 will be given below.

Table 11: The Features of Coke in 2005

	Moisture %	Ash %	Volatile %	Sulphur %	Kcal/kğ	Stability %	Hardness %
2005 Average	0.273	11.835	0.751	0.6767	6637.11	56.268	65.912

Table 12: The features of stone coals used in 2005

	Origin	Moisture %	Ash %	Sulphur %	Phosphorus %	Kcal/kğ	Stability %	Hardness %
2005 Average	USA	7.933	9.1	0.884	0.017	6978.4	52.0	63.5
	T.C	7.197	11.8	0.591	0.014	6757.0	40.1	55.5
	Canada	9.110	9.0	0.556	0.069	6876.0	57.8	64.9
	Ukraine	10.500	8.3	0.617	0.010	6741.3	53.7	63.0
	Poland	9.780	8.4	0.575	0.036	6791.0	56.8	63.2

The table data reveal that in 2005 the sulphur percentage of stone coals changed between 0.884 % and 0.575 %. Sulphur percentage of stone coal imported from USA is again higher than the others.

The usage amount and price of stone coal in 2005 is given on the Table 13 and Figure 4.

Table 13: Quantities Purchased, and Prices of Stone Coals in 2005

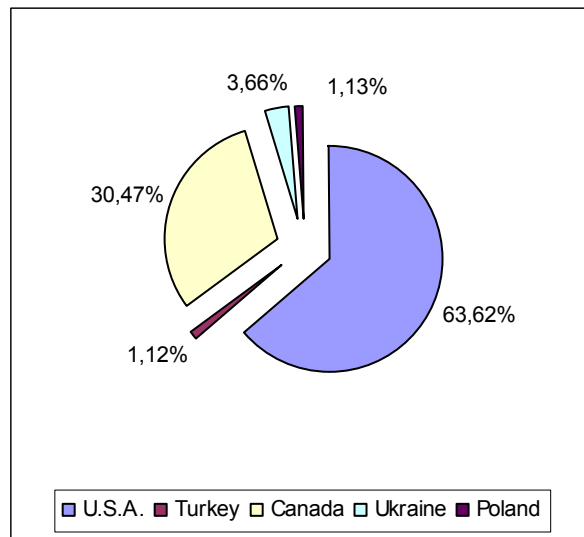| Country	Amount of coal (tone)	Percent of coal (tone)	S %	Price (USD/tone)
U.S.A.	1,275,818	0.636	0.88	$131.2
Turkey	22,500	0.011	0.59	$130.0
Canada	610,978	0.305	0.55	$137.0
Ukraine	73,376	0.037	0.62	$135.0
Poland	22,570	0.011	0.57	$134.0
Total	2,005,243	1.000		

Figure 4: Percent of Stone Coals Used in 2005 According to Origin

It is noteworthy that stone coals being imported from USA in 2005 had the highest sulphur content in 2005 (as it was also the case in 2004). However, by the amount of the stone coal imported from USA an increase of 12,6 % is to observe, namely a change from 51 % in 2004 to 63.6 % in 2005. Therefore here, there seems to remain a strong evidence why the desulphurisation cost of 2005 had risen sharply.

5.3 The Situation with the American Coal Use

5.3.1 The Reasons for the Abundant and Increasing Purchase of The American Stone Coal

It was given importance to use American coal more that other coals in 2005. There were two apparent reasons for this.

Firstly, American coal was about 5,3 US$/ton cheaper than the weighted average price of other coals, and it was 1,9 US$/ton cheaper than the weighted average price of all coals in 2005. Secondly, American coal can be found in the coal market at required abundance more easily then others.

On the other hand, certain other reasons might also influence the American stone coal purchase strategies of İsdemir from time to time. For example, raw material market in this industry is under the control of such big firms, that when proper raw material is found in any amount, although İsdemir might not need that much of the coal at the very time, there are urgencies to buy them all. In addition to such facts, cases might exist, whereby there will be nothing to do but to sign the coal contract one year before the purchase. İsdemir might be envisaged as a giant company, but actually cannot dictate much when specifying its terms of trade among giant coal dealers. If the coal

procurement policy of İsdemir is not careful enough in the world market, disastrous scarcities or high financial losses might occur.

5.3.2 Cost Saving due to the Purchase of the American Coal

5.3.2.1 Consideration and Method of Computation

To calculate saving due to using American coal which is cheaper, the average cost of 2005 might be taken into consideration. In 2005, the price of American Coal was 131.2 US$/ton and the weighted average price of other coals was 136.5 US$/ton. Thus, American stone coal was 5.2 US$/ton cheaper than the weighted average price of other purchased stone coals.

If the amount of American coal in 2005 was used in the same proportion as in 2004, the corresponding estimate in 2005 would be 1,022,674 tons, and the actual figures indicate that it would be used 253,145 tons less in 2005. So by using the cheaper coal in 2005 in the excess amount, 1,339,151 US$ should be saved in 2005 due to the choice of purchasing more of the American coal.

The amount of coke produced in 2005 is 1,285,933 tons and saving per each ton of coke will be 1.041 US$/ ton because of using American coal more.

Nearly 510 kg coke is used to produce one ton liquid hot metal. Therefore, unit saving by the production of one ton liquid hot metal is 0.53 US$/ton liquid hot metal. As a result, İsdemir gained 0.53 US$/ton liquid hot metal because of using American stone coal more, but unfortunately its sulphur content percentage is higher than others.   The corresponding data are given on Table 14.

Table 14 : Additional Saving Gained from Using American Stone Coal in 2005

The amount of American coal used in 2005 (% 63) :	1,275,818	ton
The amount of american coal used in 2004 (% 51) :	905,498	ton
Usage in 2005 according percent of american coal used in 2004:	1,022,674	ton
Amount of American coal would be used less :	253,145	ton
Price difference between American and other coals:	5.29	USD/ton
Total saving :	1,339,151	USD
The amount of coke produced in 2005 :	1,285,933	ton
Unit saving at coke production:	1.041	USD/ton
Unit saving at pig production:	0,531	USD/ton

5.3.2.2. Intermediate Result

American coal is less expensive than coals of other origin, and it can easily be found at sufficient amounts in the coal markets. Therefore, although its sulphur proportion is higher than other coals, İsdemir tended to buy American coal more and 0.53 USD/ton liquid hot metal was saved due to this choice. On the other hand, İsdemir, by the processes through using this sort of coal has to pay more to desulphurisation of liquid hot metal. How much it would be, will be examined below.

5.3.3 Cost Increase due to Desulphurisation of American Coal

5.3.3.1 Consideration and Method of Computation

The cost increase due to the intensification of desulphurisation process might be examined by investigating the value of the parameter "cost of desulphurisation/ton of liquid hot metal".

The cost of removing the extra monthly average sulphur (which is about 0.0323 %) is calculated by taking into consideration the monthly average cost report of desulphurisation factory unit in 2005. For this annual cost report is divided by 12.

There are two factors that form variable cost of desulphurisation process, and they are magnesium amount and lance number. Other cost factors can be accepted as constant cost, and are not subject to alteration. To find unit variable cost, monthly average costs of magnesium and lance were taken into account. By multiplying these unit costs with magnesium amount and lance number, which were used to remove 0.032 % sulphur in liquid hot metal, total magnesium and lance costs can be obtained. Adding these two costs together the monthly average variable cost for removing extra sulphur will be computed. The variable cost added together with monthly average constant cost would yield monthly average cost for the sake of removing 0.032 % sulphur in the liquid hot metal. It's value is 331181 US$.

Bu dividing that value to monthly average production amount, monthly average cost of removing extra sulphur per ton of liquid hot metal can be calculated. In our case, it is 1.79 US$/ ton of liquid hot metal. These results are given in Table 15.

Table 15: Desulphurisation Cost to Remove Extra Sulphur in 2005

	Mg	Lance
Unit cost	1.531 USD/kğ	1487.95 USD
Amount used for removing exta monthly average sulphur % (0,032)	112173.26 kğ	14
Monthly cost of this item (USD)	171737.26	20149.07
Variable cost for removing extra montly average sulphur % (0,032) , (USD)	191,886	
Monthly average constant cost (USD)	139,295	
Total cost (USD)	331,181	
Average monthly production amount in 2005 (ton)	185,234	
The cost of removing this extra sulphur per ton liquid hot metal	1.79 (USD/ TON L H M)	

5.3.3.2 Results

Against the gains of İsdemir by using American coal more in 2005, due to the relatively higher content of sulphur in the American coal, the increase in use caused to sulphur proportion increase in the liquid hot metal. Therefore İsdemir had to intensify the desulphurisation process to remove the extra sulphur. Due to the intensified desulphurisation process, -in terms of the same unit of measurement- monthly average cost increase 1.79 US$/ton liquid hot metal was found out

5.3.4 Comparative Situation: Should the American Stone Coal Use Continue at the Indicated Rate or Not ?

İsdemir saved 0.53 US$/ton liquid hot metal due to additional use of American coal by 12 % more in 2005. However, sulphur proportion of American stone coal is higher than other coal that might be purchased, so there became an average of 0.032 % increase in the sulphur proportion of liquid hot metal. Therefore, to remove this sulphur from liquid hot metal, İsdemir intensified the desulphurisation process, and desulphurisation process monthly average cost had thereby increased at a rate of 1.79 US$/ton of liquid hot metal.

Hence, İsdemir seems having been lost 1.26 US$/ton liquid hot metal. The immediate result will then be –without regard of the probable existence of other factors being mentioned in Section 5.3.1-, that İsdemir should not continue to use American coal at indicated rate, and tend to purchase alternative offers at the stone coal market more.

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 The Problem

İsdemir is an integrated iron and steel factory, and produces steel from liquid hot metal. Liquid hot metal is the main intermediate product of steel, and it is produced at high blast furnace from coke, sinter and pellet. Thus the sulphur proportion in the liquid hot metal is tried to be decreased at desulphurisation factory unit.

Mere observation indicated that between 2004 and 2005 a substantial increase had occurred in the desulphurisation cost. "Does the observation show a really important change, and if so, what to do to reduce the desulphurisation cost was the principal subject matter.

6.2 The Contribution

The contribution of the present study seems to be twofold. A serious, drastic cost increase problem of İsdemir had been detected and analysed, out of which suggestions to prevent it could be forwarded. Secondly, a step-by-step method of detecting the problem and its main cause had been devised, in order to furnish an example on how approaches of management could find solutions in directing engineering practices towards firm's ultimate aims.

The following summary will indicate what was done, by emphasizing steps of the method of approach.

6.3. Dealing with the Problem to Reach for the Conclusion

Firstly, the observational suspicion had to be affirmed or refuted through statistical investigation. The increase of nearly 3 US$/ton by desulphurisation cost was examined by applying "difference of means" test among 2004 and 2005 monthly data.

Strongly approved was the hypothesis that there existed a real jump between the desulphurisation costs of 2004 and 2005. In addition, Dixon's test had shown further, that the cost increase being confronted in 2005 is anomalous, in the sense that monthly data of both years are significantly incompatible.

After specifying the drastic cost shift incident, its causes were searched for. 2004 and 2005 monthly time series of 7 determining factors that might effect desulphurisation cost were subjected to stepwise regression and by means of "forward selection method", highly explanatory factors were detected out of them. Subjecting the statistical result furthermore to rationales of process in the high blast furnace, the main effect was seen to be solely depending upon the existence of coke. In 2005 the sulphur level of coke was increased remarkably.

Coke is produced from stone coal, so –as the next task- stone coals of different origins, which are bought and used in coke production were examined. It was found out that strategies of buying coals of different origins, had let in 2005 American stone coal to be purchased and used 12% more with respect to the buy of 2004. However, sulphur level of American coal is higher than those of others.

Therefore, İsdemir had gained, since American coal was the cheapest among alternatives, but had lost more, since the desulphurisation cost by using American coal had to be higher. It was computed that cost saving was attained through using American coal by 0.53 US$/ton of liquid hot metal in 2005. However, the losses occurred due to intensified desulphurisation of the American coal was more, namely 1.79 US$/ton of liquid hot metal. Hence, İsdemir lost 1.26 US$/ton of liquid hot metal by using American stone coal more in 2005.

Thus the strategy of increasing the purchased amount of American stone coal was not quite correct. İsdemir should better not continue to use American stone coal at the indicated rate.

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ENGINEERING DETAILS OF BLAST FURNACE PROCESS
TO PRODUCE LIQUID HOT METAL

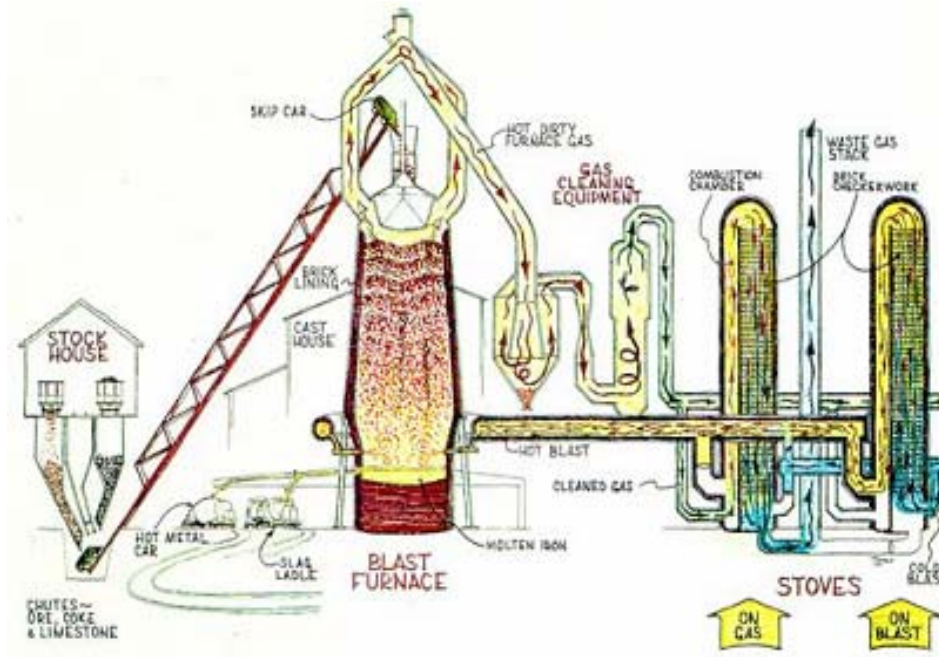### A.1 Blast Furnace Process of Producing Liquid Hot Metal

Figure 5: Pictional Outlook to Blast Furnace Process (www.steel.org)

It is noteworthy that the below stated explanation can better be followed, if reference is made to the Fiqure 5.

Iron oxides can come to the blast furnace plant in the form of raw ore, pellets or sinter. The raw ore is removed from the earth and sized into pieces

that range from 0.5 to 1.5 inches. This ore is either Hematite (Fe_2O_3) or Magnetite (Fe_3O_4) and the iron content ranges from 50% to 70%.

The so formed iron-rich ore can be charged directly into the blast furnace without any further processing. Iron ore that contains a lower iron content must be reprocessed or beneficiated to increase its iron content. Pellets are produced from this lower iron content ore. This ore is crushed and ground into a powder, so that the waste material called gangue can be removed. The remaining iron-rich powder is rolled into balls and fired in a furnace to produce strong, marble-sized pellets that contain 60% to 65% iron.

Sinter is produced from fine raw ore, small coke, sand-sized limestone and numerous other steel plant waste materials that contain some iron. These fine materials are proportioned to obtain desired chemical compositions, and then mixed together. This raw material mix is then placed on a sintering strand, which is similar to a steel conveyor belt, where it is ignited by gas-fired furnace and fused by the heat from the coke fines into larger size pieces of 0.5 to 2.0 inches.

The iron ore, pellets and sinter then become the liquid iron produced in the blast furnace with any of their remaining impurities flowing into the liquid slag.

The coke is produced from a mixture of coals. For that, coal is initially crushed and ground into a powder and then charged into an oven. In connection with the heating of oven the coal is heated up to the extent, that most of the volatile matter like oil and tar will be removed.

The so heated coal, being called "coke", is removed from the oven after surpassing 18 to 24 hours of reaction time. The coke is cooled and screened into pieces ranging from 1 to 4 inches. The coke itself would contain 90 to 93% carbon, some ash and sulfur, but compared to raw coal it is excessively pure and strong. The strong pieces of coke with a high energy value provide permeability, to provide adequate heat and hot gasses which are required to reduce and melt the iron ore, pellets and sinter.

The ingredient limestone is removed from the earth by blasting with explosives. It is then crushed and screened to a size that would range between 0.5 to 1.5 inches, to finally become blast furnace flux. This flux can be pure in containing high calcium limestone, which is either dolomithic limestone containing magnesia or a blend of the two types of limestone. Since the limestone is melted to become the slag, which removes sulphur and other impurities, the blast furnace operator may blend the different stones to produce the desired slag chemistry –with the aim of creating optimum slag properties such as a low melting point and high viscosity.

All of the raw materials are stored in an ore field and transferred to the specific warehouse before charging. Once these materials are conducted into the furnace top, they go through numerous chemical and physical reactions, while descending aback to the bottom of the furnace.

The iron ore, pellets and sinter are thus reduced, which simply means that the oxygen in the iron oxides is removed by a series of chemical reactions. These reactions occur as shown in Table A.1:

Table A.1: Chemical Reactions to Remove Oxygen from Iron Oxides
At Blast Furnace

1) $3\ Fe_2O_3 + CO = CO_2 + 2\ Fe_3O_4$	Reaction begins at 850° F
2) $Fe_3O_4 + CO = CO_2 + 3\ FeO$	Reaction begins at 1100° F
3) $FeO + CO = CO_2 + Fe$ or $FeO + C = CO + Fe$	Reaction begins at 1300° F

At the same time that the iron oxides are going through these purifying reactions, they also begin to soften, then melt, and finally trickle as liquid iron (through the coke) to the bottom of the furnace.

The coke descends to the bottom of the furnace to the level, where the preheated air or hot blast enters the blast furnace. The coke will be ignited by this hot blast, and immediately reacts to generate heat as follows:

$$C + O_2 = CO_2 + Heat \qquad (A.1)$$
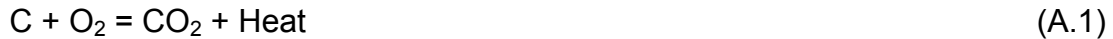
Since the reaction takes place in the presence of excess carbon at a high temperature, the carbon dioxide is reduced to carbon monoxide as follows:

$$CO_2 + C = 2CO \qquad (A.2)$$

The product of this reaction, being the carbon monoxide, is necessary to reduce the iron ore, as could be seen in the previous iron oxide reactions.

Another by-product of iron making process is slag. The liquid slag trickles through the coke bed to the bottom of the furnace, where it floats on the top of the liquid iron since it is less dense.

In addition to molten iron and slag, hot and dirty gasses are met as further intermediate products. These gasses exit the top of the blast furnace, and proceed onwards through gas cleaning equipment, where particulate matter is removed from the gas and the gas will be cooled down.

It should be pointed out that this gas has a considerable energy value, so it is burned as a fuel in the "hot blast stoves", which in turn will be used to preheat the air entering into the blast furnace to become "hot blast".

The blast furnace is the first step in producing steel from iron oxides. The first blast furnaces appeared in the 14'th Century, and produced one ton per day. Blast furnace equipment is in continuous evolution and modern, giant furnaces produce up till 13,000 tons per day. Even though the equipment has been improved and higher production rates can be achieved, the processes occurring inside the blast furnace remained almost the same (www.steel.org).

A.2 Slag Formation

In the blast furnace, slag is formed by melting and combining of foreign oxides in the iron ore, together with addition material, and coke ash under high temperature. The oxides that formed slag are Al_2O_3 , SiO_2 , CaO , MgO , FeO , MnO and sulphur compounds which predominantly include CaS and MgS. Sometimes, there can also be unimportant amounts of chrome, potassium, sodium in the slag.

The processes of melting iron ore, sinter or pellet occur prior to slag formation. These processes enable passing from solid state to liquid state. The bigger the heat interval oxides require for passing from solid state to liquid state, the bigger volume the sticky mass will have -which fills the gap inside coke and prevent movement of gas. Therefore softening heat interval of material, that form slag, should be low enough.

Slag forming process has three phases.

The structure of coke ash will effect the final formation of slag. Generally the sources of Al_2O_3 are the materials consisting iron. Regular working of blast furnace is related with the quality of hot liquid iron and distinctive features of the slag. In this sense, the most important features of slag are fusion, melting temperature, viscosity, and the capacity of collecting sulphur.

A.3 Case with Sulphur in the Blast Furnace

A.3.1 Sulphur Sources

Sulphur is loaded to blast furnace together with materials which include iron ore, but also coke (which is used for reducing materials that form slag), and certain additional materials. Out of these, materials which contain the highest sulphur ratio are respectively coke coal and sinter. Correct action would be to have low sulphur content among these loading materials. Moreover, also coke ash, which unfortunately contains high amounts of sulphur is to be loaded to blast furnace.

In the coke coal, sulphur exists in forms of CS complex and FeS. However, its quantity should not be more than %1 in practical applicat6ion..

It should be noted that sulphur exists in the iron ores also in other forms of FeS, $CaSO_4$, $BaSO_4$, MnS. Again its existence should not surpass 1 %.

Sulphur remains in the sinter as FeS, $CaSO_4$ and CaS. The quantitative proportions of these compounds depend upon the basicity.

A.3.2 Distribution of Sulphur Within the Blast Furnace Products

Sulphur in the blast furnace is shared by slag, pig (ie. hot, liquid raw iron) and blast furnace gas -according to the constellation of raw materials and conditions of blast furnace. About 4 % of sulphur emanates out of the blast furnace together with gas.

At 1500° C, sulphur can be solved inside the pig until 0.9 %, but this is too high. In practice, it is expected to lie around 0.06 % or lower.

Solving rate of the CaS is 9 % inside blast furnace slag.

A.3.3 The Movement of Sulphur in Blast Furnace

When the coke comes to tuyeres' level, sulphur in the coke should remains at about ½ or ¾ of the initial amount. Some parts of the sulphur which go out of the blast furnace leave the blast furnace filled with gas. Other and rather overwhelming proportion of sulphur react, and finally form FeS and CaS.

Pig, when reaches to the hearth of blast furnace, is rather saturated with sulphur and it releases some parts of sulphur to gas. Some of the sulphur in the gas will then blend with the material inside stack again. Therefore, a circulation occurs between the hearth and stack. Temperature of the coke consumption effect determines the amount of sulphur which evaporates out of the blast furnace together with gas. If coke consumption increases, the amount of sulphur would decrease, because the amount of blast furnace gas increases.

The real distribution of sulphur between slag and pig occurs, when the pig (which contains high amounts of sulphur) passes through slag under the tuyeres' level, and it releases a large part of sulphur to slag -at the time when the pig is in the state of dropping.

A.3.4 The Control of Sulphur in the Blast Furnace

The limestone descends in the blast furnace and remains as a solid while going through the reaction,

$$CaCO_2 = CaO + CO_2 \qquad\qquad (A.3)$$

This reaction requires energy and starts at about 1600°F. The CaO resulting from it is used to remove sulphur from the iron which is necessary before the hot metal becomes steel. This sulfur removing reaction is:

$$FeS + CaO + C = CaS + FeO + CO \qquad\qquad (A.4)$$

The CaS becomes part of the slag. The same reaction might also occur with MgO.

The input used (e.g. sinter and iron ore) have little control on the percentage Al_2O_3 in the slag, which itself would make the slag viscous and sulphur transfer from metal to slag difficult. For the production of quality hot metal (pig), it is essential to identify and optimize the various parameters eg. raw material quality, burden distribution, blowing conditions (Özgen , et. al. , 1991).