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THE KALDO PROCESS

by

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The Kaldo process, developed and licensed by Stora Kopparbergs Bergslags AB, Sweden, has been described in several papers (e.g. 1, 2).

The characteristic feature of this oxygen steel making process is that the reactions take place in a fast rotating furnace with a slightly inclined axis. The rotational speed can be varied from 0 to 40 RPM. The oxygen is injected above the bath through a water-cooled lance, which is introduced through the opening of the furnace. The waste gas, which mainly consists of carbon-dioxide, leaves the furnace through the same opening. A schematical view of a 30 tons furnace is shown in Fig.1.

The inclined position of the furnace allows the lining at the closed end face, like the cylindric wall, to be cooled by the metal during every turn and so contributes to the heat transmission from the gases to the metal. This cooling of the lining makes it possible to burn the carbon-monoxide developed in the bath to carbon-dioxide with oxygen above the metal and make this heat useful for the process.

The iron content of the slag and thereby the chemical reactions can be controlled by the rotational speed of the furnace, the position of the oxygen lance and the oxygen flow.

KALDO plants in operation and under construction

The first commercial operation of the KALDO process was started in a 30 tons[x] furnace at the Domnarvet Steelworks, Sweden, in 1956. In this plant the production is based on basic bessemer iron. The surplus heat from the chemical reactions is used for direct reduction of iron ore to steel.

After one year's operation experience at Domnarvet and through qualitative investigations, SOLLAC in France decided to erect one 120 ton KALDO furnace for the production of deep drawing sheet of highest quality from basic bessemer iron, and about the same time the Grängesberg Company in Sweden chose the KALDO process for its new steel works in Oxelösund, having in mind the possibility of using either high or low-phosphorus ore. This plant consists of two 120 ton KALDO furnaces. At Sharon Steel Company of USA two more KALDO furnaces of 135 tons each were put into operation

Tab. 1 shows a list of KALDO furnaces at present in operation and under construction. From this table it can be seen that the process is mainly chosen for refining of high-phosphorus iron. The only company which so far has erected a KALDO plant for refining of only low-phosphorus iron is Sharon, where the production program consists of a large variety of steel qualities with high and low carbon content including alloy steel. Also at Sanyo low-phosphorus iron will be used for a similar steel program.

Heat economy and raw material requirement

Due to the direction of the oxygen jet the oxygen partly burns with the carbon-monoxide, generated in the bath, to carbon-dioxide. The heat developed from complete combustion of carbon to carbon-dioxide is more than three times the heat developed from the formation of carbon-monoxide, and therefore the carbon content of the charged metal is a very useful fuel for the KALDO process.

With proper position of the oxygen lance it is possible to oxidise as an average 90% of the carbon to CO_2, whereby 6000 kcal/kg C can be utilized (3). On account of this large amount of heat which has to be transferred from the gas phase to the bath the KALDO process needs a longer blowing time than the LD process and its modifications, where very little heat transfer between gas and liquid phase takes place. Compared with other processes where the heat as in KALDO is supplied from above, e.g. the open hearth process, the heat cycle of the KALDO process is remarkably short.

Tab. 2 shows the average charge composition per ton steel and also the total heat utilized for scrap melting and ore reduction, which gives a good comparative value when both scrap and ore are used as coolants.

The metallic charge at SOLLAC including Fe in ore is 1089 kg/ton corresponding to a steel yield of almost 92%.

The table shows that at Sharon, where low-phosphorus iron is used, the available heat for scrap melting is nearly the same as in the case of high-phosphorus iron at SOLLAC.

On account of less slag the steel yield from low-phosphorus iron is higher than from high-phosphorus iron. The reason for less nonspecified iron loss at SOLLAC compared to Sharon is a better scrap quality.

The KALDO process is, compared to other oxygen steel processes, in the first hand of interest in cases, when cheap scrap is available and the supply of blast furnace metal is limited. When there is lack of steel scrap it can also be economic to use the surplus heat of the KALDO process for direct reduction of ore to steel as the case is in Sweden.

Charge composition when only ore is used as cooling agent is given for Domnarvet's 30 tons furnace in the last column of tab. 2. The ore contains 2.1% P_2O_5. This does not influence the phosphorus content of the steel but increases the phosphorus content of the slag, which is sold as fertilizer along with basic bessemer slag.

Flexibility

The KALDO process has a great flexibility which can be summarized in the following items:

1. Choice of raw material

Pig iron of any composition can be used.
Scrap, cold pig iron or ore are acceptable as cooling agent.
Ore can be used also in fine-grained condition, e.g. as concentrate.
Scrap addition can be increased furthermore or more ore can be reduced by addition of carbon, giving a high calorific yield.

2. Steel composition

The effective process control makes it easy - independent of charge composition - to widely vary and mix the production program and with close tolerances of analyses and tapping temperature manufacture various types of steel, high and low in carbon, including alloyed specifications.

It is also an advantage that changing to another steel specification, on account of modified rolling mill program, easily can be made during the heat. If it should be necessary to keep the steel in the furnace, due to delays in the casting shop, the temperature can easily be corrected thanks to the heat developed by complete combustion of carbon to CO_2. In case of continuous casting the good temperature control is of still more importance.

Lining durability

Lining wear is relatively high in the KALDO process, and this fact has been claimed to be a serious draw-back in comparison with other oxygen steel processes.

At Domnarvet, where the furnace lining consists of tar dolomite, the wear is about 5 mm per heat in the most exposed part of the lining, corresponding to a dolomite consumption of about 20 kg/ingot ton. At SOLLAC, where very heavy scrap is used, dolomite consumption is about 24 kg/ingot ton excluding about 5 kg/t burnt magnesite (4). At Oxelösund the consumption is about 13 kg dolomite and 5 kg magnesite per ton steel.

Normally the number of heats per lining is 80-90 at Domnarvet against 50-60 at SOLLAC. In spite of 20% scrap in the charge the lining life at Oxelösund is almost the same as in Domnarvet. Some campaigns with more than 110 charges indicate, however, that there are still great possibilities to further improve the lining life at Oxelösund without using more expensive refractories.

Generally tar dolomite has been used for the lining of the KALDO furnaces in Europe. Recently an Austrian company has developed a new burnt magnesite brick, which at Domnarvet has given 272 heats, corresponding to a refractory consumption of only 6 kg/ingot ton. Cast magnesite bricks have been used for complete linings at Sharon with 156 heats as the best result so far.

Engineering

The furnace is made in a double conical shape with the length equal to 1.5 times the internal shell diameter. The heat size in ingot tons for a KALDO furnace is 0.7 - 0.8 times the 3rd power of this diameter, corresponding to a specific volume which is less than 2/3 of the same common for LD converters.

To secure continuous operation two exchangeable vessels are used in Domnarvet and SOLLAC. This system involves lower capital cost than two complete furnaces, and furthermore less space is required. Oxelösund as well as Sharon has two complete furnaces with one in operation at a time. This system allows more time for inspection of the machinery and secures also in other respects a more reliable operation. With the improved refractories now available it is also possible to keep 2 of 3 furnaces in continuous operation.

On account of the high CO combustion inside the furnace the waste gases contain only a small content of CO. For combustion and control of the gas temperature in the hood less air is consequently needed in the KALDO process than by top blowing. On account of this the required capacity of the gas cleaning plant is about 50% of the same for an LD plant producing the same amount of steel and

Productivity

The results obtained at Domnarvet and SOLLAC, in which plants the process has been operated for the longest time, are given in tab. 3.

The effective average operation time at Domnarvet's 30 tons furnace is 72 minutes and in addition to that 10 minutes for fettling and maintenance. The total time corresponds to a weekly production of 3700 ingot ton. The maximum production obtained so far is 3844 ton, but in general the production is limited because of oxygen shortness. Delays of this or similar reasons are not included in the figures given in the table.

At SOLLAC the non-blowing time is somewhat longer due to scrap charging and the after-rotation practice. Also in this case delay time, not depending on the KALDO operation, is excluded.

Economic valuation

A cost comparison at Domnarvet between KALDO and the basic bessemer process, of which the latter according to common opinion gives lower steel price than any other steel method, is shown in tab. 4a and 4b.

According to table 4a the charge cost for KALDO is significantly lower due to less requirement of pig iron. About 10% of the steel is namely obtained from iron contained in the ore, the price of which is only 40% of that of the blast furnace metal. Besides, the Fe-yield is 2% better than in the bessemer. Also in the bessemer operation the surplus heat is mainly utilized for reduction of ore.

The table shows that the conversion cost is higher in the KALDO than in the bessemer process. but at Domnarvet this extra expense is balanced by lower charge cost, making the KALDO steel 1.6% cheaper than the bessemer steel.

In table 4b the conversion cost is split up in some items of special interest. Thus it shows that the lining cost (which includes wrecking, relining, all refractory materials and heating) in spite of relatively big wear is only 3.4% of the steel price compared with 2.1% at the bessemer steel. From the table it can easily be calculated that the total lining cost in the KALDO process corresponds to a difference of about 4% in charge cost and thus easily can be compensated for.

The saving on charged material, as a consequence of the good heat utilisation in the KALDO process, can also be made with scrap as coolant if the scrap is cheaper than the hot metal. This can be illustrated through a comparison with the LD process, using hot metal with low phosphorus content and about 1% Si. As a ground for this comparison the figures appearing in United Nations' ECE publication "Comparison of Steel-making Processes", issued 1962 (5) have been used.

Table 5 shows the metallic charge for LD operation with 25% scrap according to table 20 in the ECE publication and for the KALDO operation at Sharon according to table 2 above. In order to have a more correct comparison, the material required for KALDO is, however, adjusted to the same teeming loss which has been calculated with in ECE's publication.

If the price ratio between scrap and hot metal is called P_sR and the pig iron costs P_{HM} per ton, the saving for metallic charge in the KALDO process with the consumption shown in table 5 will be

$$\Delta C_{Ch} = P_{HM}(0.179 - 0.159 \cdot P_sR)$$

The saving, as calculated from this equation, is given in Fig.4. Normally the price of high grade commercial scrap is about 80% of the hot metal price. In this case the cost for the metallic charge in KALDO is $0.052 \cdot P_{HM}$ lower than in LD, i.e. about 10 Sw.Fr. per ton. In many cases the price of scrap is still lower and with an increased amount of LD plants, which only melt the scrap circulating in the plant, the supply of commercial scrap for other processes will probably increase. KALDO can in this case very well compete with the open hearth and arc furnaces for melting such scrap. In the ECE publication (5) the conversion cost in KALDO furnaces is calculated as 70% of the same in open hearth and only 60% of the electric melting if the power cost is 0.06 Sw.Fr./kWh.

In the above comparison no profit that can be derived from metallurgical performance of the process has been considered. With the independence of the hot metal composition and freedom to make use of scrap, cold pig iron or ore, also as fine-grained concentrate, there is a great possibility to choose the charge composition which is the cheapest available.

As an example production of deep drawing sheet of highest quality (max 0.015% P) from basic bessemer iron can be mentioned. Very important at such a production is the quality yield, which means how much of the produced quantity that can be used for the purpose it is intended for and therefore is paid for at full price. Besides the mathematical profit of a high quality yield a uniform and high quality always satisfies the customers, and thus increases the possibility to keep full production - [illegible] factors in all steel making processes.

Some further discussion of the conversion cost could be of interest with reference to the ECE publication (5), in which these costs are calculated per ingot ton for different processes. As the casting cost when producing the same steel grade must be almost independent of the steel making process, the conversion cost for different steel processes could, however, be better compared if final additions, tapping and casting were excluded.

The casting cost is not specified in the ECE publication, but for the calculations shown in table 6 a conversion cost of 14 Sw.Fr./t ingot and additional 3 Sw.Fr./t capital cost has been assumed. The last figure is probably, due to bigger heats and building, too low for an open hearth shop, but the difference is significative for the process and for that reason the same deduction has been made for all processes selected in table 6. As distinguished from ECE's calculations the oxygen has been included in the conversion costs in table 6. Finishing and casting have been excluded also from the total production cost but the figures are still referring to ingot weight, which has no influence on the relative conversion and capital costs.

From the table it is clear that the conversion cost in all the selected steel processes is very small compared to the other costs, mainly the charged material. Consequently the largest profit can be made by increasing the steel yield and utilizing the cheapest metallic charge composition.

The ECE publication (5) has also calculated the investment cost for different steel processes and thereby also considered the investment required for iron making and other material needed. In table 7 some of these investment costs for a big integrated steel works (3 mill ton) are listed. For the KALDO process the investment in iron making and coke production is, however, adjusted to 40% scrap in the charge, which is a reasonable figure for both common basic bessemer iron and low-phosphorus iron with about 1.0% Si. The investment cost for oxygen is also covering power generation for the oxygen plant. The KALDO process is in table 10 only compared with the more common methods for refining blast furnace metal to steel but both 50 and 30% scrap in the charge for the open hearth has been included.

In spite of a 16% higher investment cost for a KALDO shop, compared to LD and LDAC, the total investment cost for an integrated steel works using the KALDO method is 10% lower than for a plant based on the LD or LDAC processes. This is a consequence of the lower hot metal requirement for KALDO production when scrap is used as coolant.

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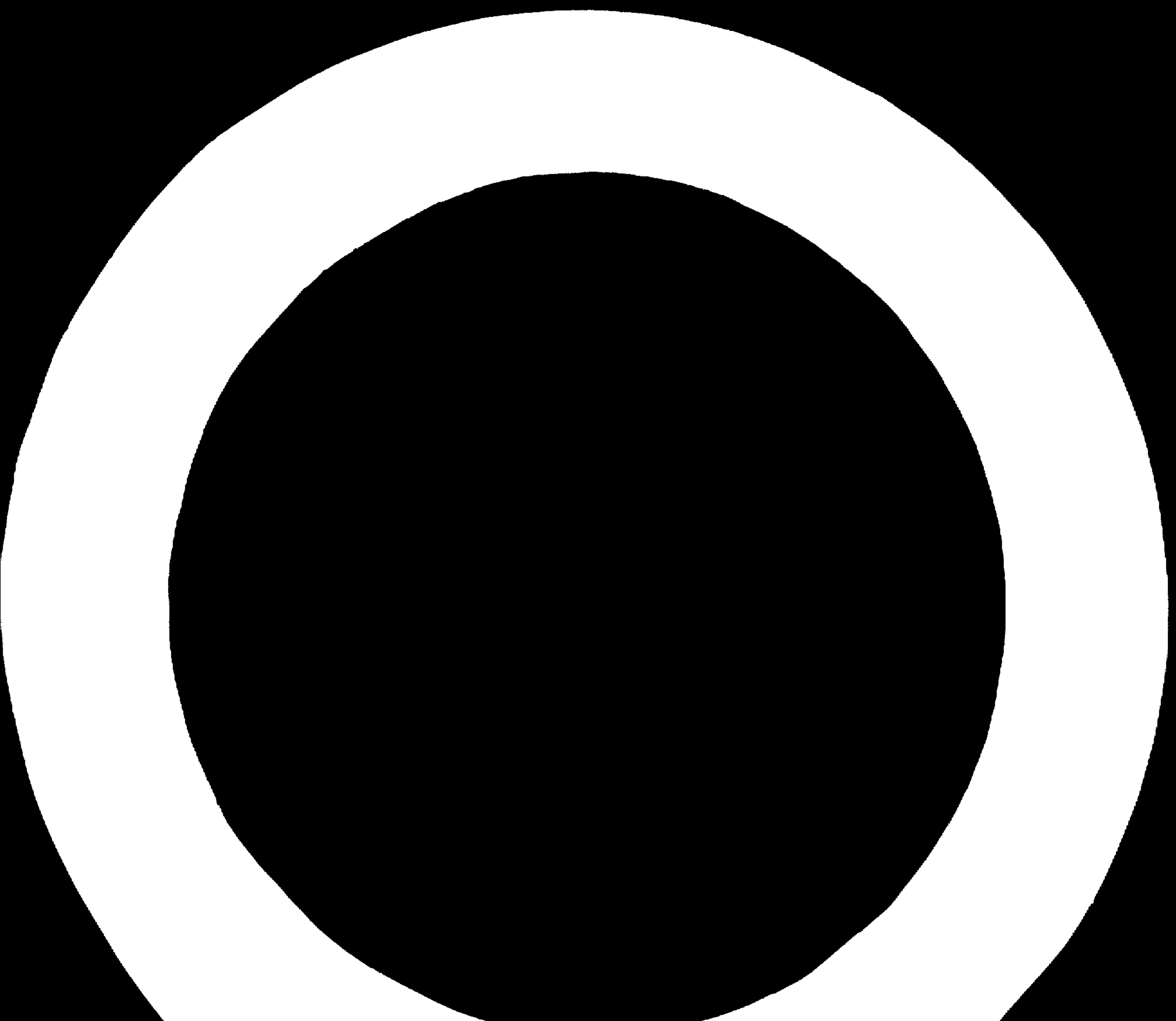
5. Economic Commission for Europe, Geneva, 1962 (ST/ECE/STEEL/4): Comparison of Steel-making Processes.

FIGURES



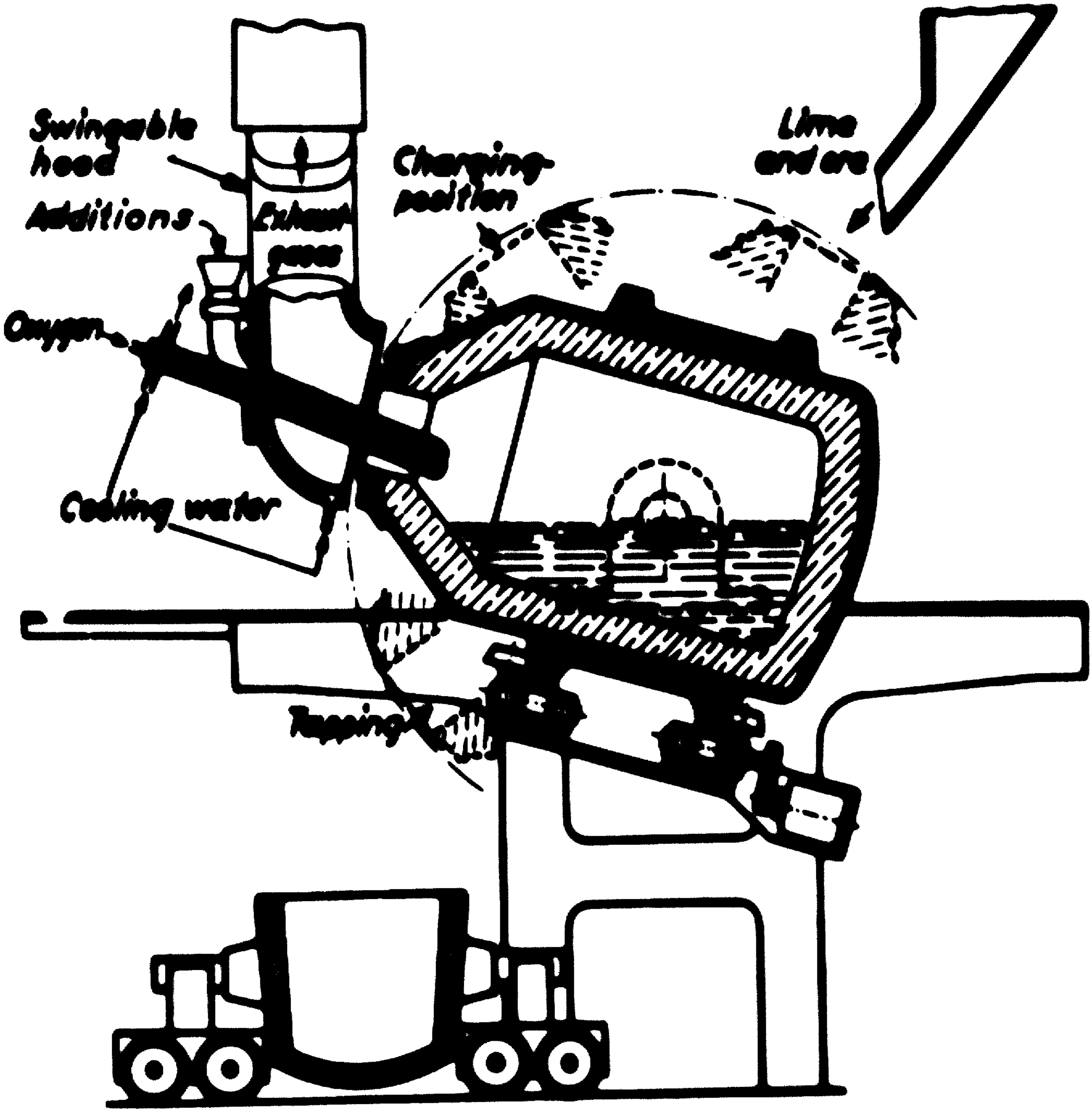
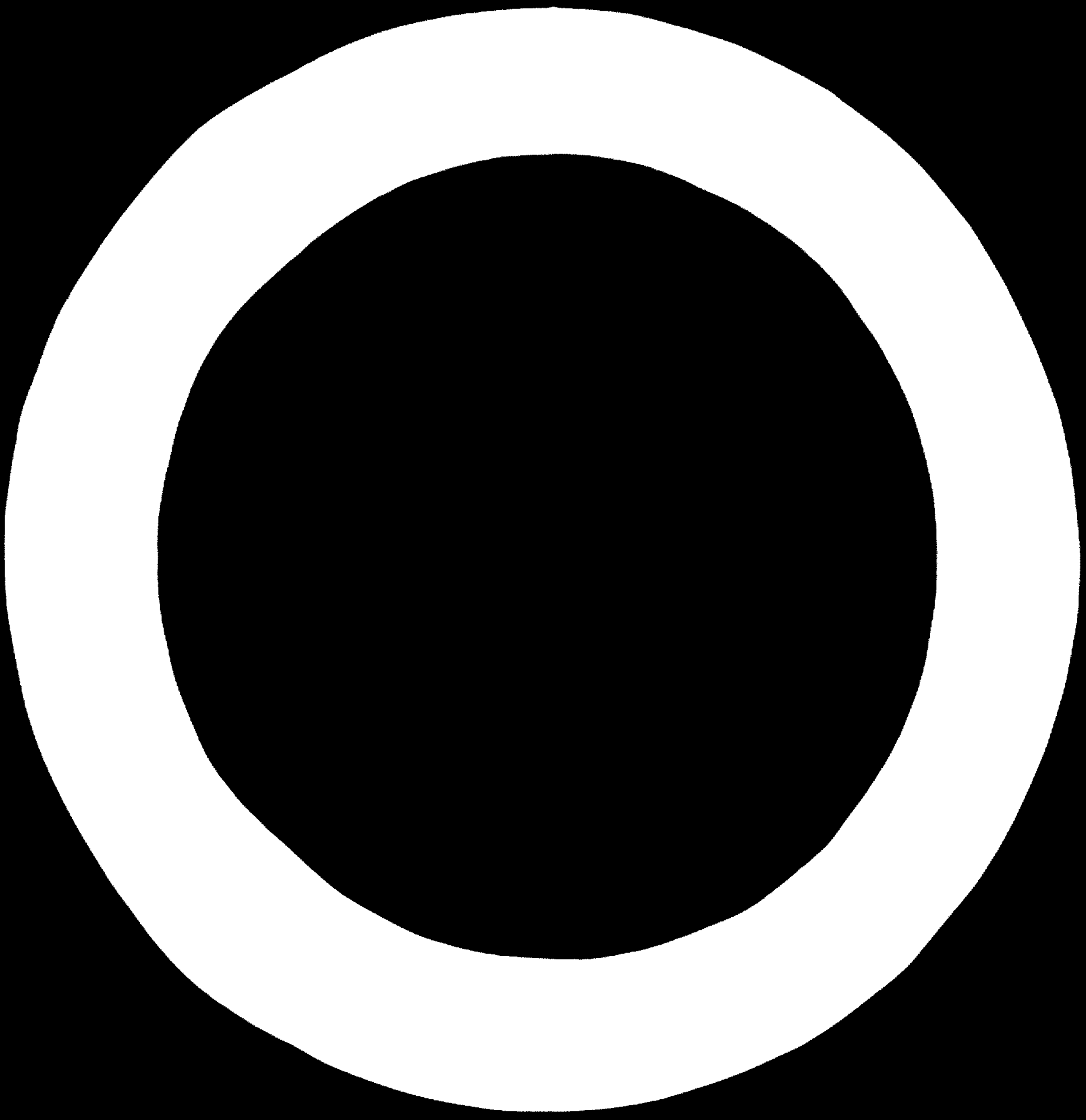

Swingable head
Additions
Exhaust gases
Charging position
Lime and ore
Oxygen
Cooling water
Tapping

Figure 1



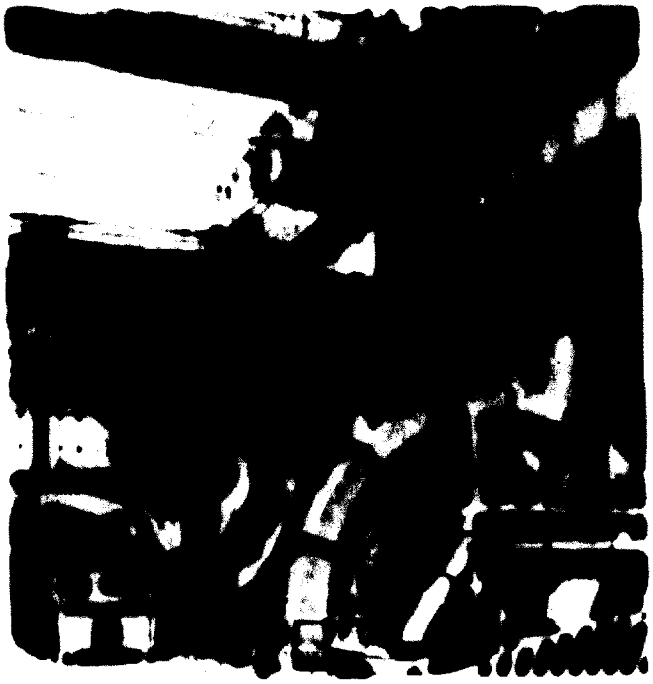
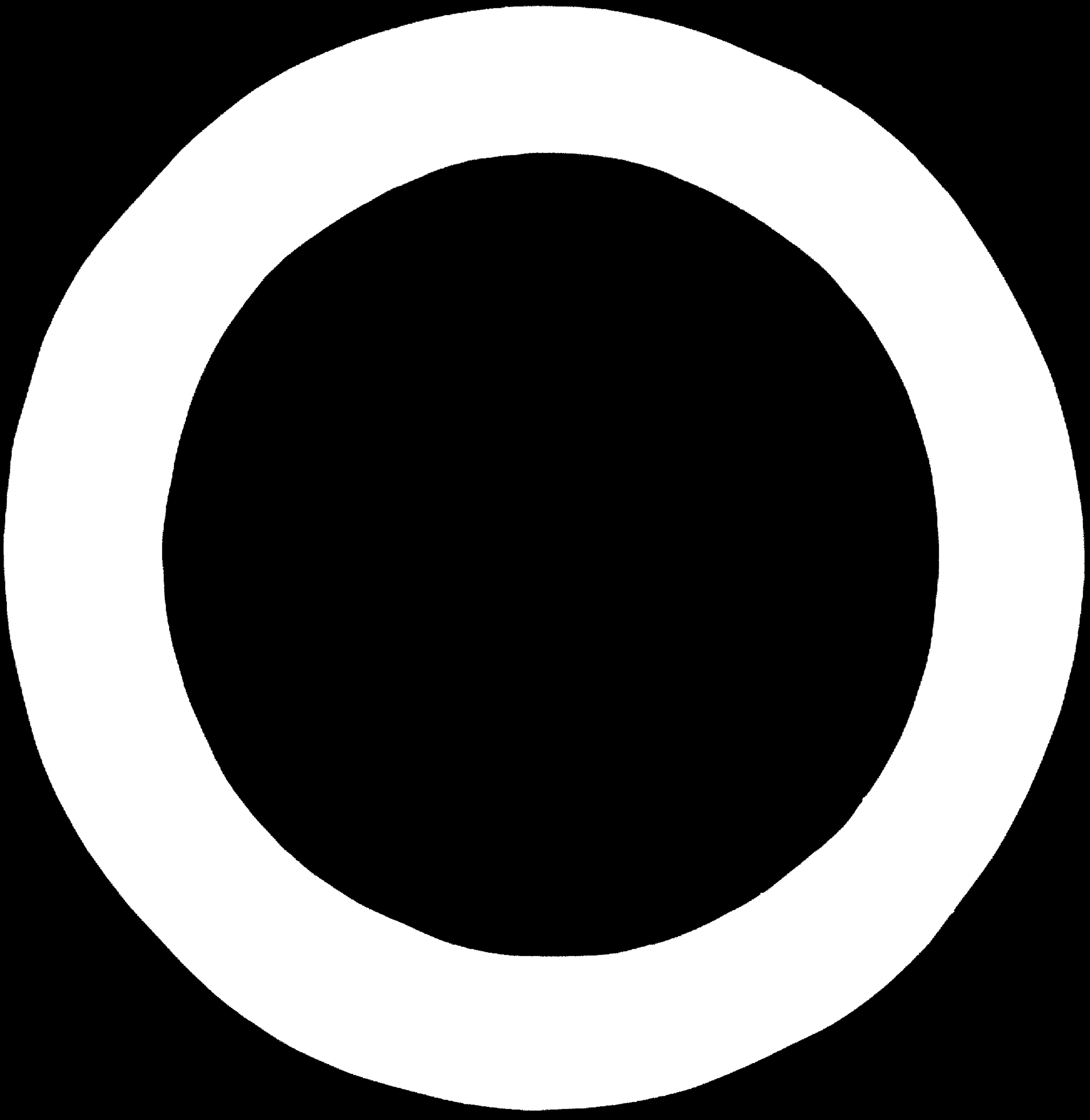


Figure 2

Figure 3



Cost difference between LD and KALDO for metallic charge.

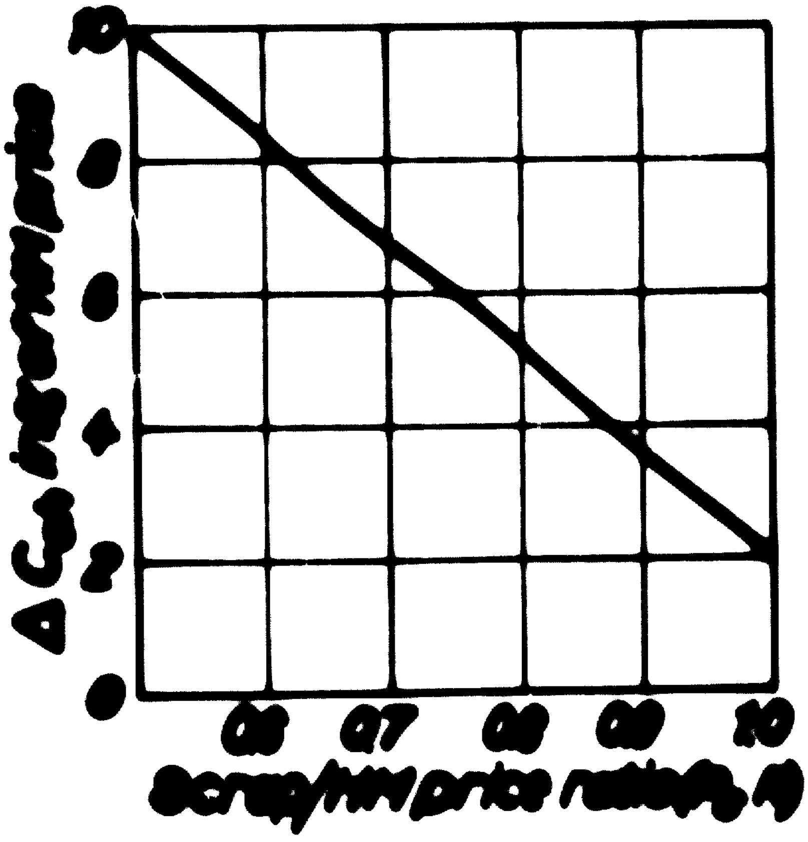
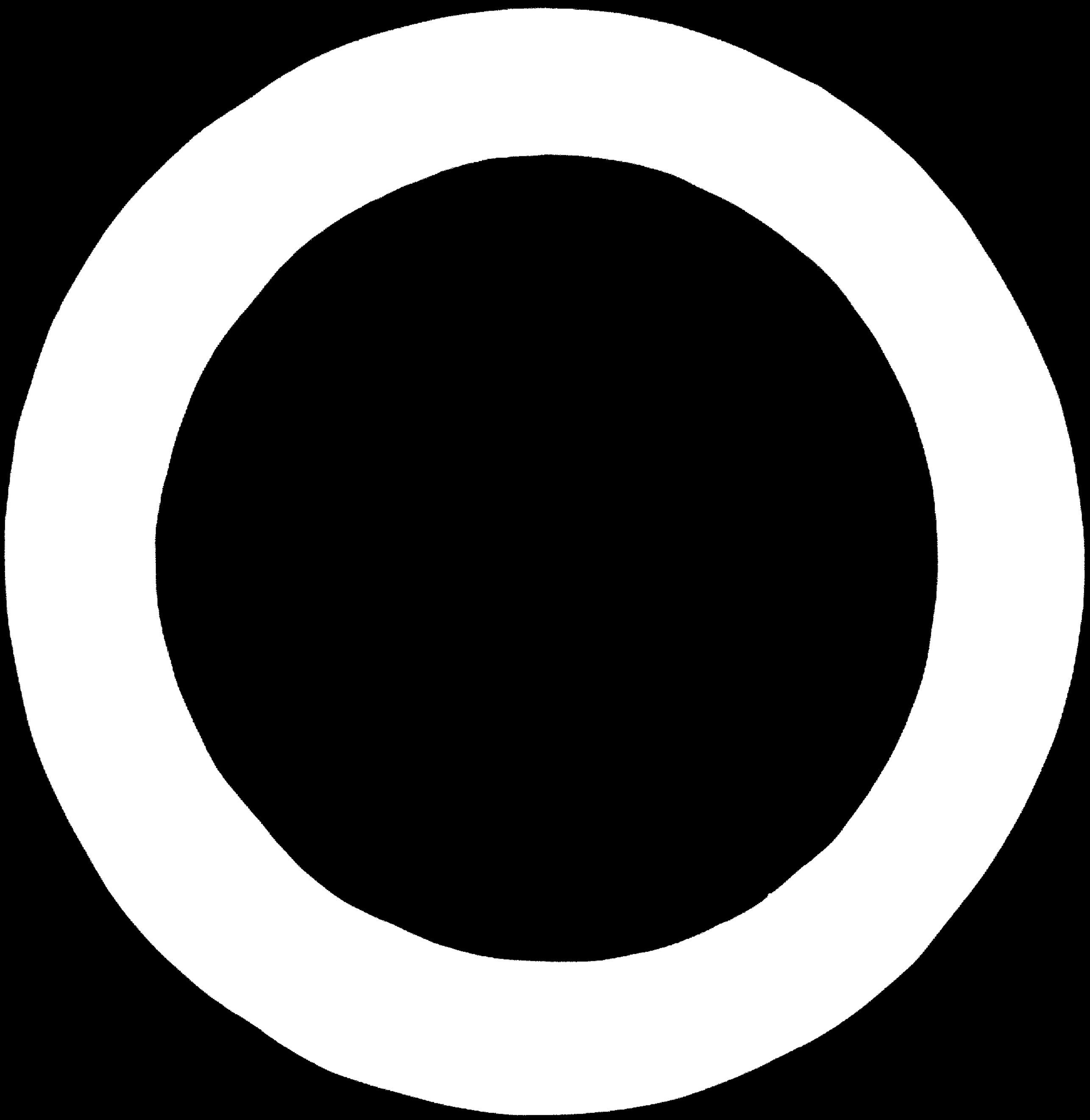


Diagram 4



TABLES

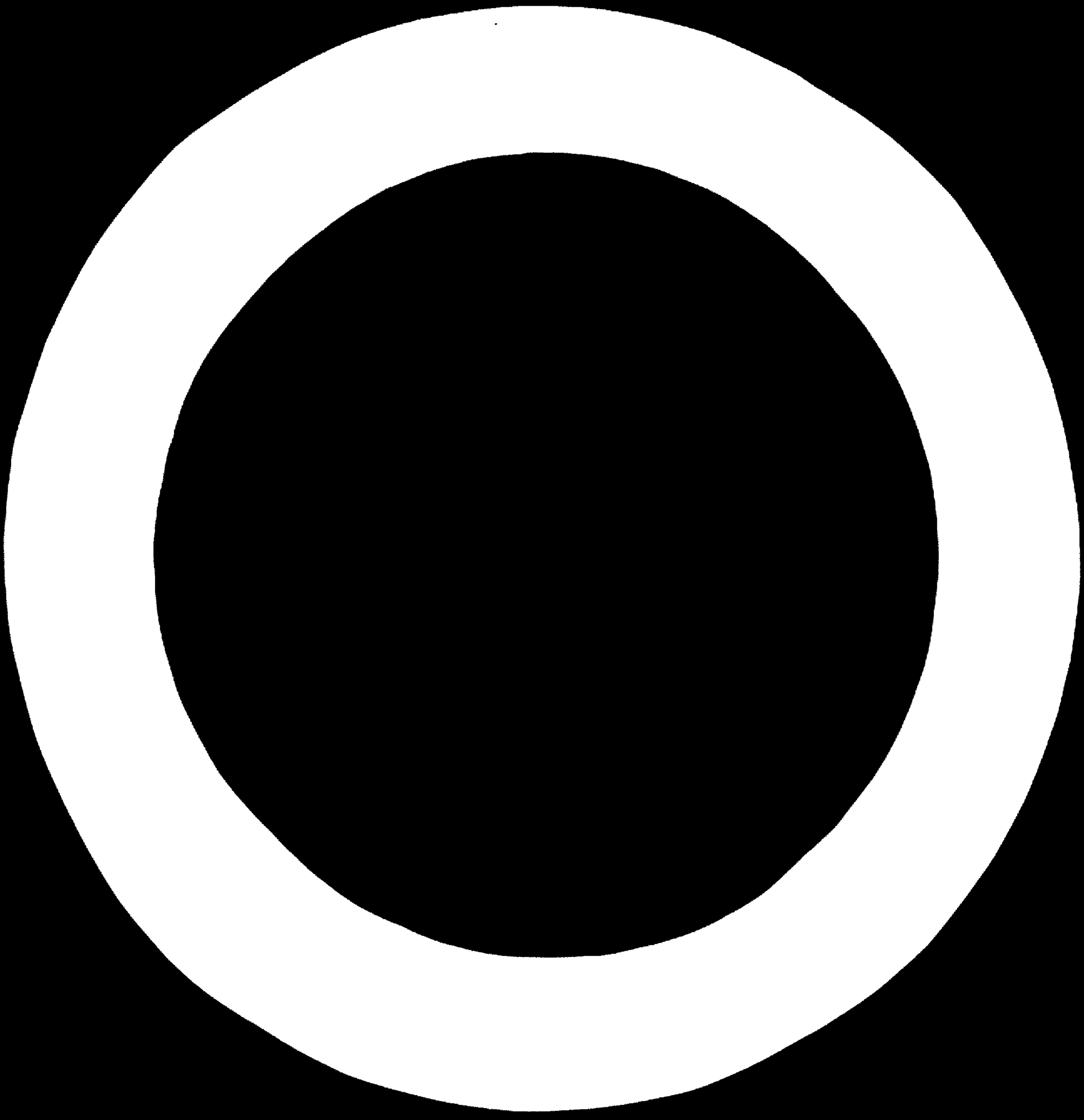


Table I

Kaldo Plants in Operation and under Construction (Aug. 1st, 1963)

Operating from	Name of firm and location of plant	Country	Furnaces		Annual Capacity (1000 tons)	Hot metal	Coolant	Main Products
			Number	Heat size (tons)				
1956	Stora Kopparbergs Bergslags AB, Domnarvet	Sweden	1[1])	30	150	High P (1.8)	Ore	Plate, Sheet, Wire
1960	SOLLAC, Seremange	France	1[1])	120	500	High P (1.8)	Scrap	Deep drawing sheet
1961	Grängesbergsbolaget, Oxelösund	Sweden	2	120	450	Low P (0.03)	Ore (Scrap)	Plate
1962	Sharon Steel Corp., Sharon, Pa	U S A	2	135	900	Low P (0.1)	Scrap	High and low carbon Alloy steel
1963	Consett Iron Co.Ltd., Consett, Durham	England	2	120	450	Med.P (0.6)	Scrap/ ore	High carbon
1963	Park Gate Iron and Steel Co.Ltd. Rotherham	England	2	80	400	High P (1.8)	Scrap/ Ore/ Cold Pig	High and low carbon Alloy steel
1963	Shelton Iron and Steel Ltd, Stoke-on-Trent	England	2[1])	90	350	High P (1.4)	Scrap	High and low carbon (Continuous casting)
1964	Norrbottens Järnverk AB, Lulea	Sweden	1	60	200	High P (1.8)	Ore	Sheet
1965	Stanton and Staveley Ltd, Stanton by Dale, Derby	England	1[1])	70	280	High P (1.8)	Ore/ Scrap	High grade foundry iron
1965	Stora Kopparbergs Bergslags AB, Domnarvet	Sweden	2[1])	70	550	High P (1.8)	Ore	Plate, Sheet, Wire
1965	Sanyo Special Steel Co.Ltd, Himeji	Japan	2	60	300	Low P (0.25)	Scrap/ Cold Pig	High and medium carbon, Alloy steel

[1]) With exchange vessel

The weights are in metric tons

Table 2

Charge composition per metric ton of liquid steel

			SOLLAC	Sharon	Domnarvet
Hot metal analyses		%	3.6 C 0.5 Si 0.35 Mn 1.75 P	4.45 C 1.0 Si 0.4 Mn 0.08 P	3.6 C 0.3 Si 0.7 Mn 1.85 P
Blown metal analyses'		%	0.05 C	0.25 C	0.08 C
Charged:	Hot metal	kg	670	650	1016
	Scrap	kg	405 (0.05% C, 0.3% Mn)	430	-
	Ore	kg	20 (pellets)	8 (pellets)	170 (61% Fe as Fe_3O_4)
	Lime	kg	103	40	135
Oxygen consumption		nm^3	62	58	60
Total metallic charge incl. Fe in ore		kg	1089	1085	1120
Oxidised C, Si, Mn, P		kg	41	36	64
Oxidised iron in slag		kg	25	13	32
Further iron loss incl. Fe in dust		kg	23	36	24
Utilised heat for scrap melting and ore reduction		kcal	161×10^3	153×10^3	212×10^3
Dto per metric ton of hot metal		kcal	240×10^3	235×10^3	209×10^3

Table 3

Production figures

			SOLLAC	Domnarvet
Vessel size:	Inside shell diameter	mm	5500	3420
	Length	mm	8100	5300
Liquid steel per heat		ton	123	30
Heat cycle:	Blowing	min	41	45
	Others	min	36	27
	Fettling and maintenance	min	8	10
	Total	min	85	82
Production		ton/h	87	22

Tab. 4a and 4b

Table 4a

Production Cost for KALDO Steel in relation to Basic Bessemer Steel at Domnarvet

(Per ton liquid steel)

	Quantity, kg		Relative cost, %	
	BB	KALDO	BB	KALDO
Charged:				
Hot metal	1110	1016	90.59	82.91
Scrap	10	-	0.65	-
Ore (61% Fe)	45	170	0.88	3.34
Lime	160	135	5.10	4.31
Credit:				
Slag	290	270	6.45	6.01
Scrap	20	16	1.22	0.98
Total charge cost			89.55	83.57
Conversion cost			10.45	14.86
Production cost, total			100.00	98.43

Table 4b

Specification of Conversion Cost

	BB	KALDO	Diff. between KALDO and BB
Refractories and relining	2.09	3.44	1.35
Blast and oxygen	1.45	2.40	0.95
Furnace operation incl. gas cleaning	1.86	3.19	1.33
Raw material and slag transport	0.74	0.66	- 0.08
Share of steel dpt common cost, administration and capital	4.31	5.17	0.86
Total	10.45	14.86	4.41

Table 5

Base for calculation of cost for metallic charge when using low-phosphorus iron with 1.0% Si.

Kg/t ingot at 2.8% teeming loss.

	LD	KALDO
Hot metal	847	668
Scrap	283	442
Total metallics	1130	1110
Furnace loss	102	82
Teeming loss	28	28

Table 6

Conversion and capital cost for liquid steel by different methods

(Sw.Fr. per ingot ton)

(Calculated from ECE-report, ref. 5)

HM quality	Low-phosphorus					High-phosphorus			
Process	OH		LD	KALDO		BB with O_2	LDAC	KALDO	
HM/Scrap %	70/30	50/50	75/25	70/30	55/45		75/25	70/30	55/45
Conversion cost	32.7	33.6	16.7	21.8	21.3	19.2	19.3	21.8	21.6
Capital cost	11.4	11.4	4.2	5.4	5.4	3.0	4.8	6.0	6.0
Total prod. cost	266.8	246.4	257.3	251.2	232.2	240.8	235.6	229.6	222.4
Conv. cost % of total	12.3	13.6	6.5	8.7	9.2	8.0	8.2	9.5	9.7
Capital cost % of total	4.3	4.6	1.6	2.1	2.3	1.2	2.0	2.6	2.7

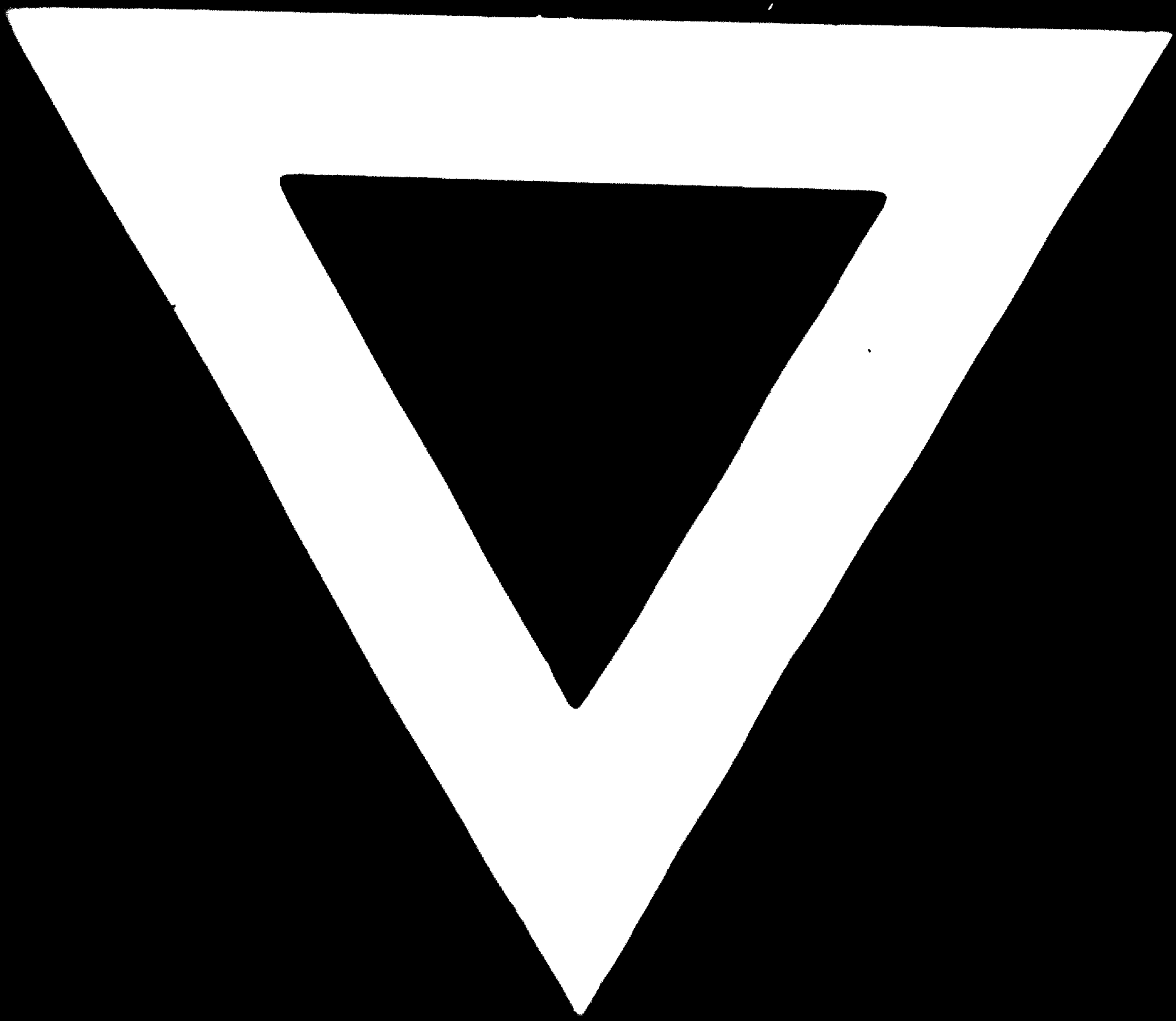
Table I

Investment cost for different steel processes

(Sw.Fr. per ton of annual capacity)

(From ECE-report, ref. 5)

HM quality	Low-phosphorus				High-phosphorus		
Process	OH		LD	KALDO	TB with O_2	LD-AC	KALDO
Hm/Scrap	70/30	50/50	75/25	60/40		75/25	60/40
Steel shop	120	120	60	70	50	65	75
Oxygen production	9	7	14	15	7	15	16
Ironmaking incl. coking plant	145	104	165	130	176	162	128
Total	274	231	239	215	233	243	219
% of OH 50/50	119	100	103	93	101	105	95



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