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This way the process was developped is quite interesting in that a number of facts were accepted and a number of other facts were neglected. If we had to do it again, as for many other techniques, it would be certainly quite different. So we must look afresh to the rather special points of these processes.

First, they were intended to use very fine concentrates, especially from taconites in the UNITED STATES or from finely ground magnetites in Sweden : so, the idea of balling this fine material was quite natural and proved to be a fine solution. Now that we know the advantages of uniform small sized burden in blast furnaces, this can be questioned and for relatively coarse concentrates or fines from screening or crushing of direct shipping ores, another way of forming the "green agglomerate" such as briqueting or extruding may be the right answer.

Next, it was considered essential to use large tonnage of concentrate, the main effort was directed towards development of large machines such as strands of 2 000 t/day and shaft furnaces of 500 and, later, 1 000 t/day.

Third, these processes were mainly directed towards using these fines concentrates and the overall thermal efficiency of the furnace was not considered as essential. It was considered as fortunate to have such excellent results in shaft furnaces but the first industrial results in RESERVE MINING heat hardening strands, were not too impressive. This is quite clear in table I where we must also note the important consumption of solide fuel.

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More recent developments are not so directly connected with the use of finely ground concentrates and two main reasons may explain them :

- first, the interesting results obtained in blast furnaces (see later, IVth part of this paper) lead to the possible application of the pelletining processes to different raw materials;

- second comparisons with sintering lead to improve the process, especially in designing larger plants producing better pellets with a smaller heat consumption.

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T A B L E A U I - EVOLUTION DES CONSOMMATIONS THERMIQUES DES INSTALLATIONS D'AGGLOMERATION EN BOULETTES DE LA PERIODE 1956 - 1958 -

Machines de la première génération traitant des concentrés de magnétite à :

60 à 65 % Fe

9 à 8 % SiO_2

Atelier	Hoyt Lakes Erie Mining		Silver Bay Reserve Mining	
Année	Anthracite	thermies totales*	Anthracite kg/t	thermies totales*/t de boulettes
1956	diminution et	-	de l'ordre de	400
1957	suppression	-	25 à 40 kg	320
1958	progressive	-	↓	210
1959	↓	210		175
1960		190	3,5	170
1961		160	on vise la suppression totale de l'anthracite, sur les nouvelles machines	-
1962	↓	150		-
	sur les 4 fours les plus récents, on arrive à 125 thermies/t			

* en dehors de l'anthracite, la couverture des besoins thermiques est faite par du fuel-oil (N° 5).

This lead :

- to design and operate strand of capacity up to 6 000 t/day,

- to operate with magnetite concentrate with heat consumption below 200 thermies/t of pellets and, sometimes, down to 60 thermies,

- to the development of the GRATE KILN process derivated from the LEPOL process largely used in the EUROPEAN cement industry.

BALLING -

This is the first step and is aimed to transform the fine ore or concentrate in a green agglomerated product; in the real sense of pelletizing, this step is accomplished by rolling the wet materials to build successive layers of the pellet by a kind of "snowball" process. Water film between particles makes a bond and superficial forces are, indeed, the cause of the bonding.

Without elaborating on the details of balling theory such as what was published by TIGERSCHIÖLD and ILMONI (4), it is clear that the size analysis or, more precisely, the specific surface of the concentrate has to attain a certain level to be able to ball it.

As a matter of fact, for hematite or magnetite concentrates, specific surfaces have to be in the order of 2 000 cm2/g or more and this corresponds roughly to :

100 % minus 100 Tyler mesh (147 microns)

75 % minus 326 Tyler mesh (43 microns).

Coming to fine ores or concentrates with limonite, goethite, siderite, etc. it seems possible to have such large specific surface at coarser sizes due, probably, to the porosity of such ores. As a matter of fact, it is indeed possible to ball these ores with size analysis such as these indicated at figure 4.

In commercial plants, balling is made in apparatus with a moving surface such as drums, cones, discs, etc. Figure 5 gives an example of such plant; it must be noted that, especially with balling drums, great care must be paid to sizing of the greens pellets and to the recirculation of small "seeds"

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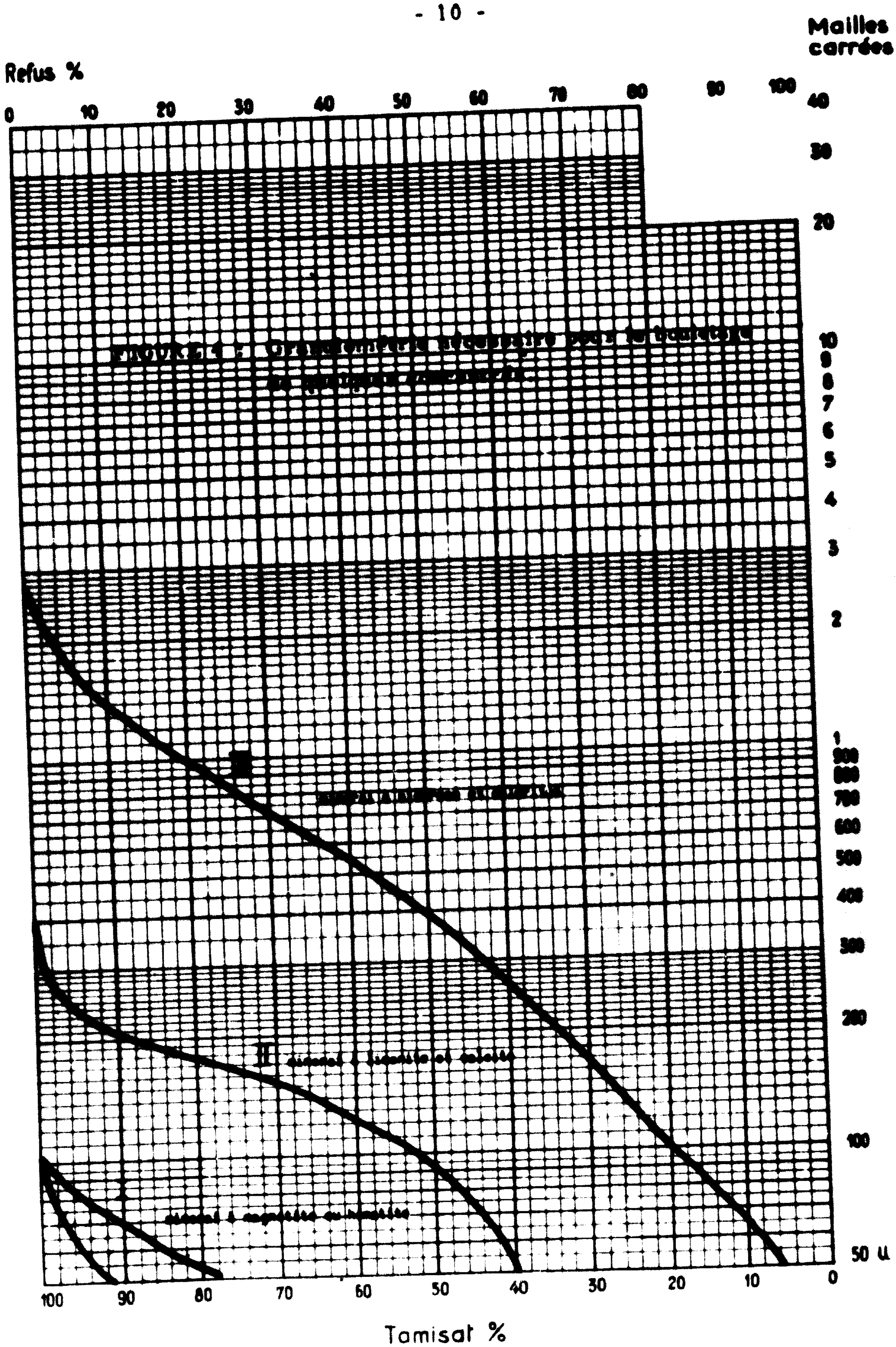
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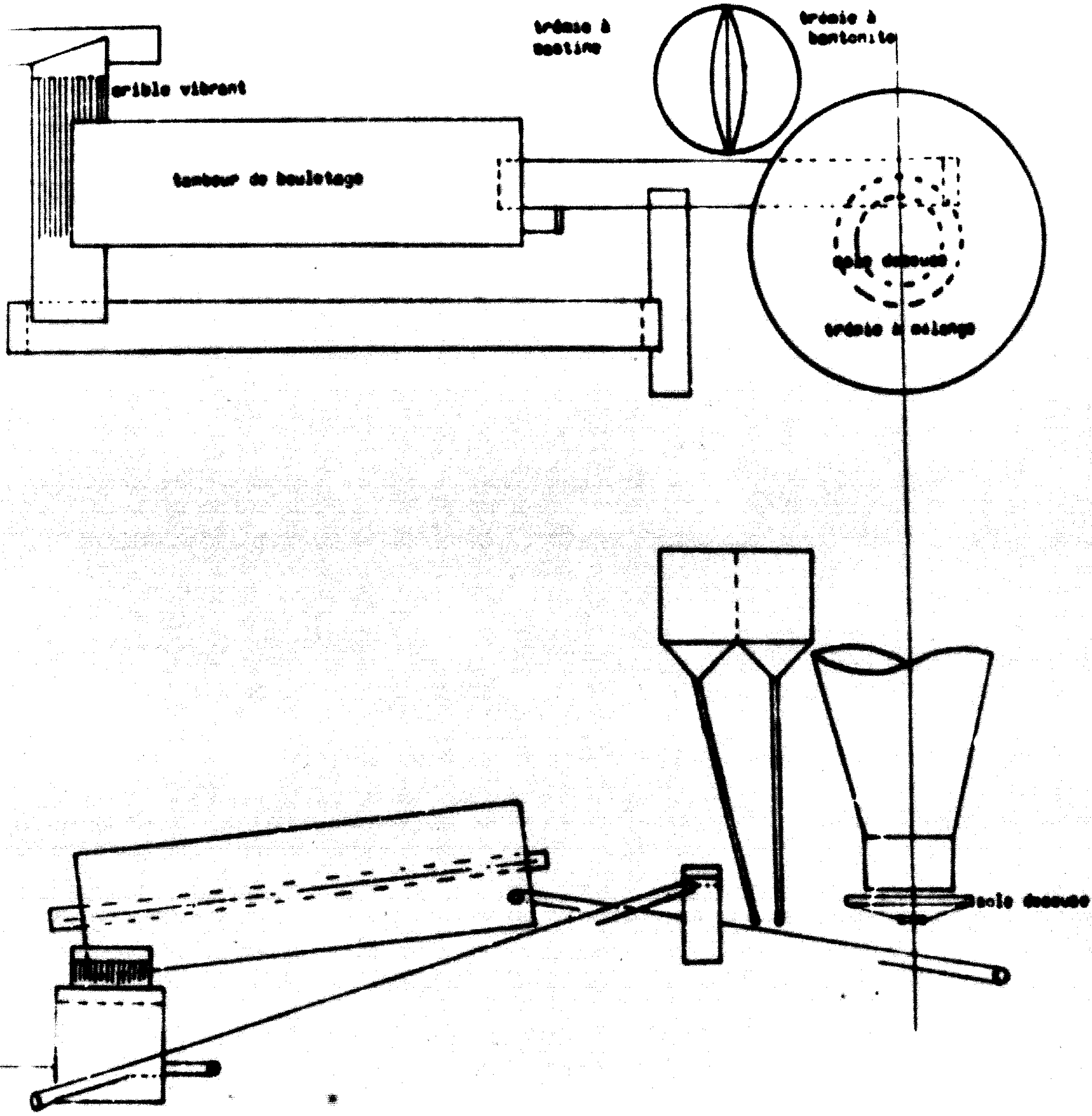

<u>FIGURE 5</u> : **Installation classique d'un tambour de bouletage (d'après M.J. GREAVES et A. ENGLISH).**

If concentration leads to coarse products or if we are starting from natural fines, the size of these raw materials has to be further reduced by a regrinding operation before balling. An example of such a practice can be found in Canada at the CAROL LAKE plant where a pelletizing plant of 5,5 millions tons per year capacity has just recently been started. As we mentionned before, if the raw materials are relatively coarse, such a practice can be questioned and some thought should be given to other ways of creating green briquets, compacts or extruded products.

FIRING OF PELLETS -

The green pellets resulting from the balling step are to weak to be used in industrial plants without firing except in some special operations such as :

- the tests performed by US BUREAU OF MINES with green pellets in an experimental blast furnace (5);
- the commercial preheating in shaft furnaces of green pellets to feed an electric smelting furnace; this practice initiated by ELEKTROKEMISK (6) is facilitated by the use of a binder (cement), which leads after a certain time of stockpiling to a hardening of the pellets.

As a rule, however, pellets are hardened by firing them in a special furnace; the "agglomeration" of the grains is mainly effected by a recrystallisation of iron oxides and this point was studied by a number of authors such as COOKE, BAN, STOWASSER (7) (8).

Many different furnaces could be used but, just now, three different processes only have been developped, based :

- on the shaft furnace,
- on the continuous strand,
- or on the LEPOL or GRATE KILN process.

Firing of pellets in shaft furnaces :

Historically, this was the first process developped at industrial scale to fire pellets and this is associated with the names of PICKANDS MATHER and BETHLEHEM STEEL in the UNITED STATES.

A basic design of such furnaces is given at figure 6 (this refers to the furnaces of ERIE MINING). All the furnaces of large capacity are rectangular and we shall give later (see table III)sections of furnaces in actual operation or being built; they vary from 7.8 to 9.15 m2 for productions of 500 to 1 000 t/day which means from 60 to 110 t/m2 x day.

Smaller furnaces with circular or rectangular sections have been built in a number of countries, especially in Sweden. It must be noted that pilot plant furnaces have been built for production around 10 to 20 t/day and commercial furnaces from 40 t/day up to 1 000 t/day.

Firing of pellets on a continuous strand :

The initial research work has probably been made at the research laboratory of ALLIS CHALMERS in the UNITED STATES. These initial tests have led to a number of different industrial machines which have been gradually improved. Figure 7 gives, as examples, the evolution in design of Arthur G. McKEE machines at RESERVE MINING and figure 8 gives design of DRAVO and LURGI strands. As it will be seen later (table III), from the first units of 2 000 t/day, actual machines ranges between 1 000 and 6 000 t/day.

Firing of pellets in a LEPOL or GRATE KILN process :

More recently, the use of this LEPOL process, pretty well developped in the EUROPEAN cement industry, was initiated to fine pellets. As it can be seen at figure 9, this is a combination of a rotary kiln with predrying and preheating on a continuous strand or "grate".

POSSIBLE FUTURE DEVELOPMENTS -

We have defined pelletizing as a process where we first ball or form by any other method a "green agglomerate" which is to be heat hardened in a second step. In that way, it is opposed with hot forming such as it is now being developped in the hot briquetting processes.

But, it is possible to improve the pelletizing process or, at least, to modify it in changing the conditions of this thermal operation. It is usually an oxidising operation where magnetite or any ferrous iron is converted almost totally in hematite. It was, of course, thought that a reducing heat hardening could be achieved. Advantages can listed :

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Figure 6.

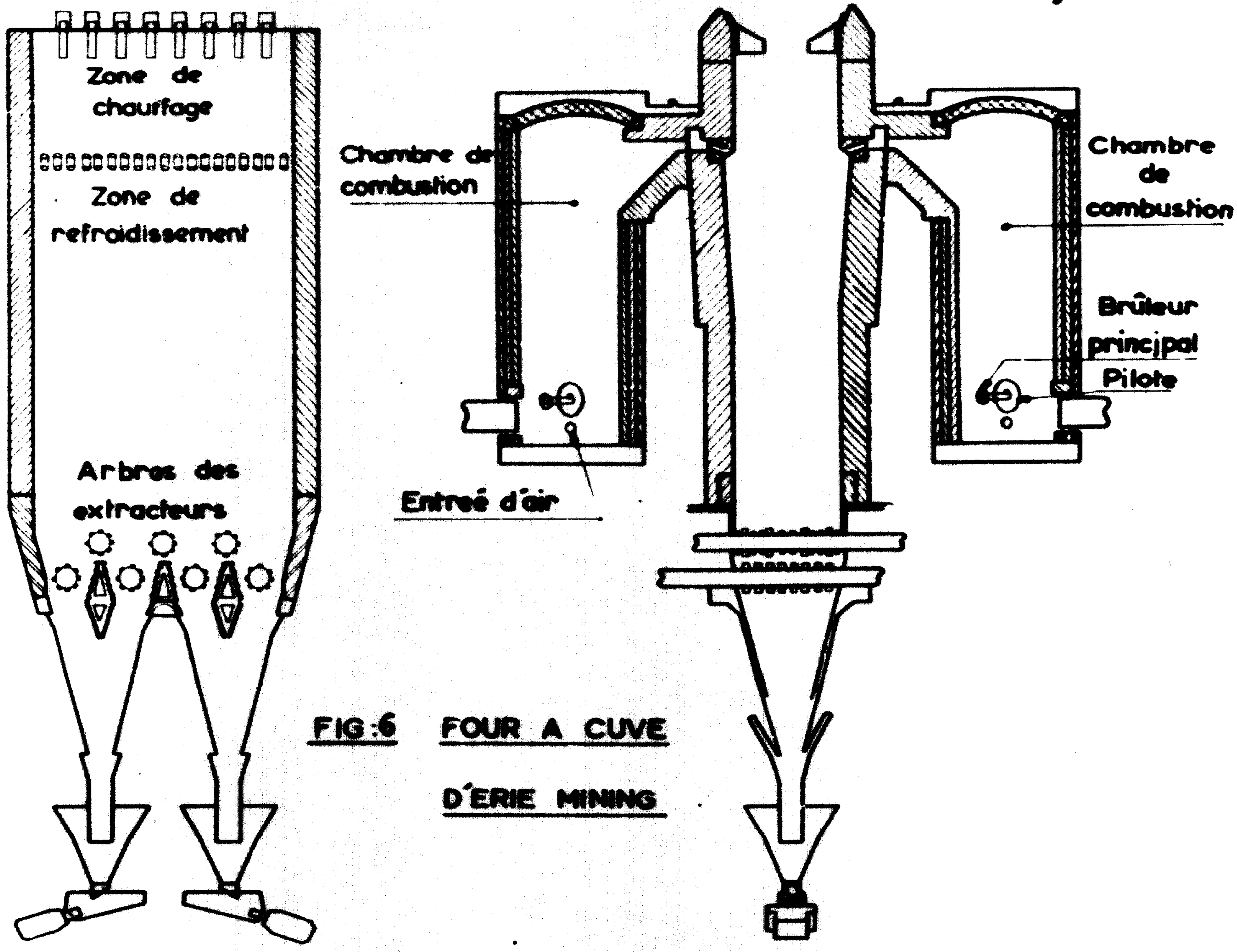
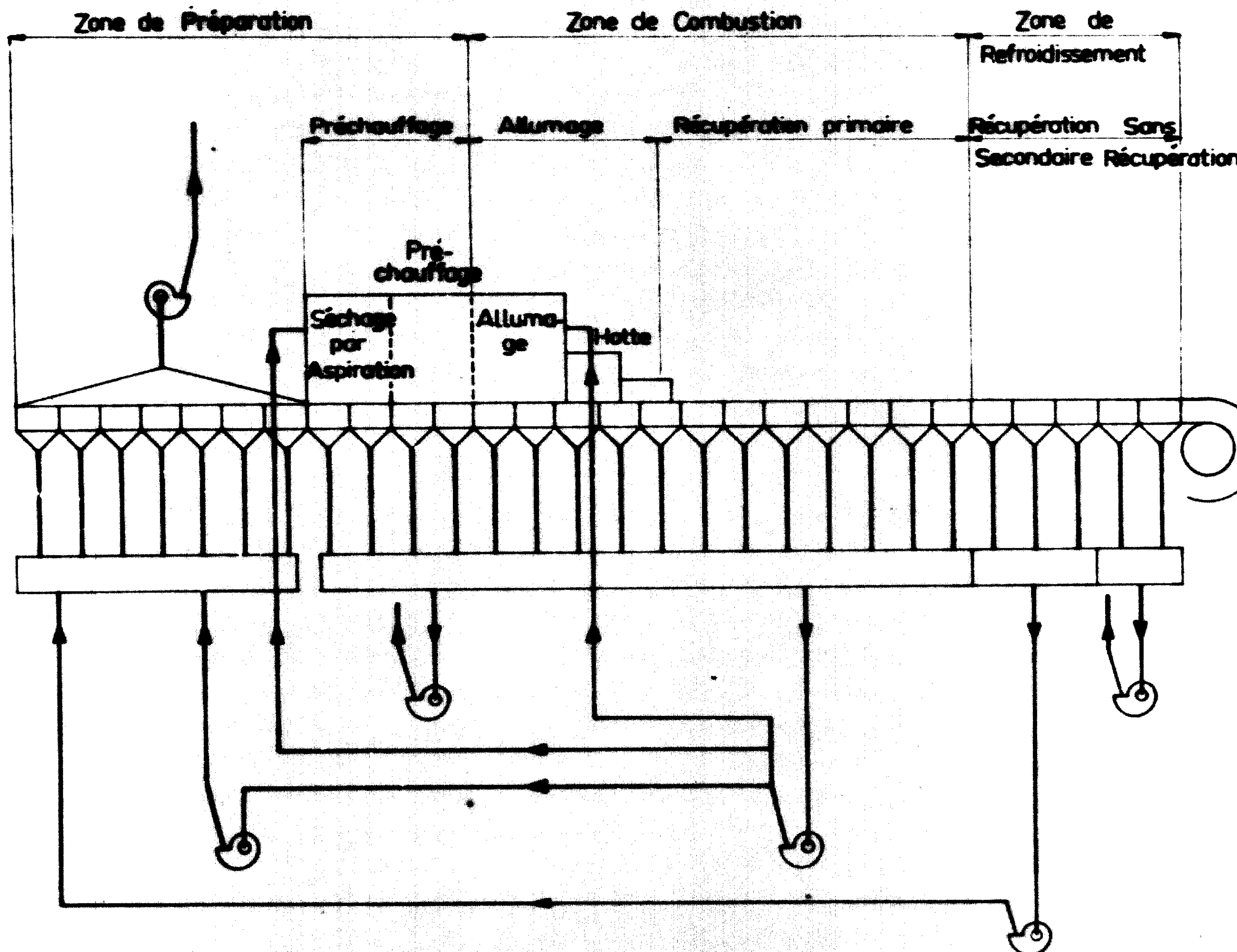


FIG :6 FOUR A CUVE D'ERIE MINING

Figure 7

GRILLE CONTINUE DE RESERVE MINING

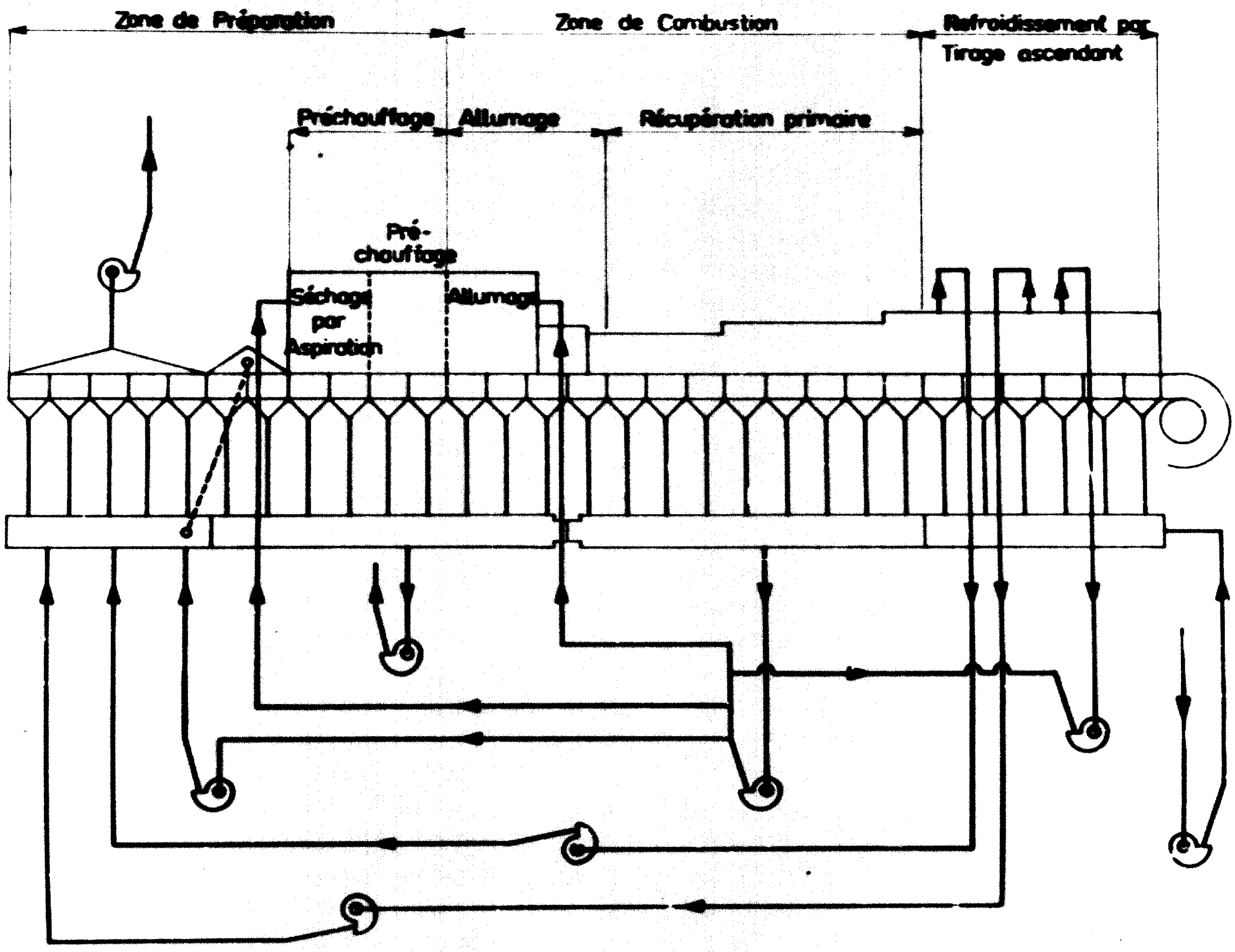
TYPE ORIGINAL



GRILLE CONTINUE DE RESERVE MINING

Figure 7 bis

TYPE MODIFIE



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INDUSTRY TO DEVELOPING COUNTRIES

11-26 NOVEMBER 1963

STEEL SYMP.1963/
Technical Paper/A.5
31 October 1963

ENGLISH
Original: FRENCH

PELLETIZING

by

J. Astier, IRSID, France

GE.63-13669

FIGURE 8

GRILLE CONTINUE DRAVO

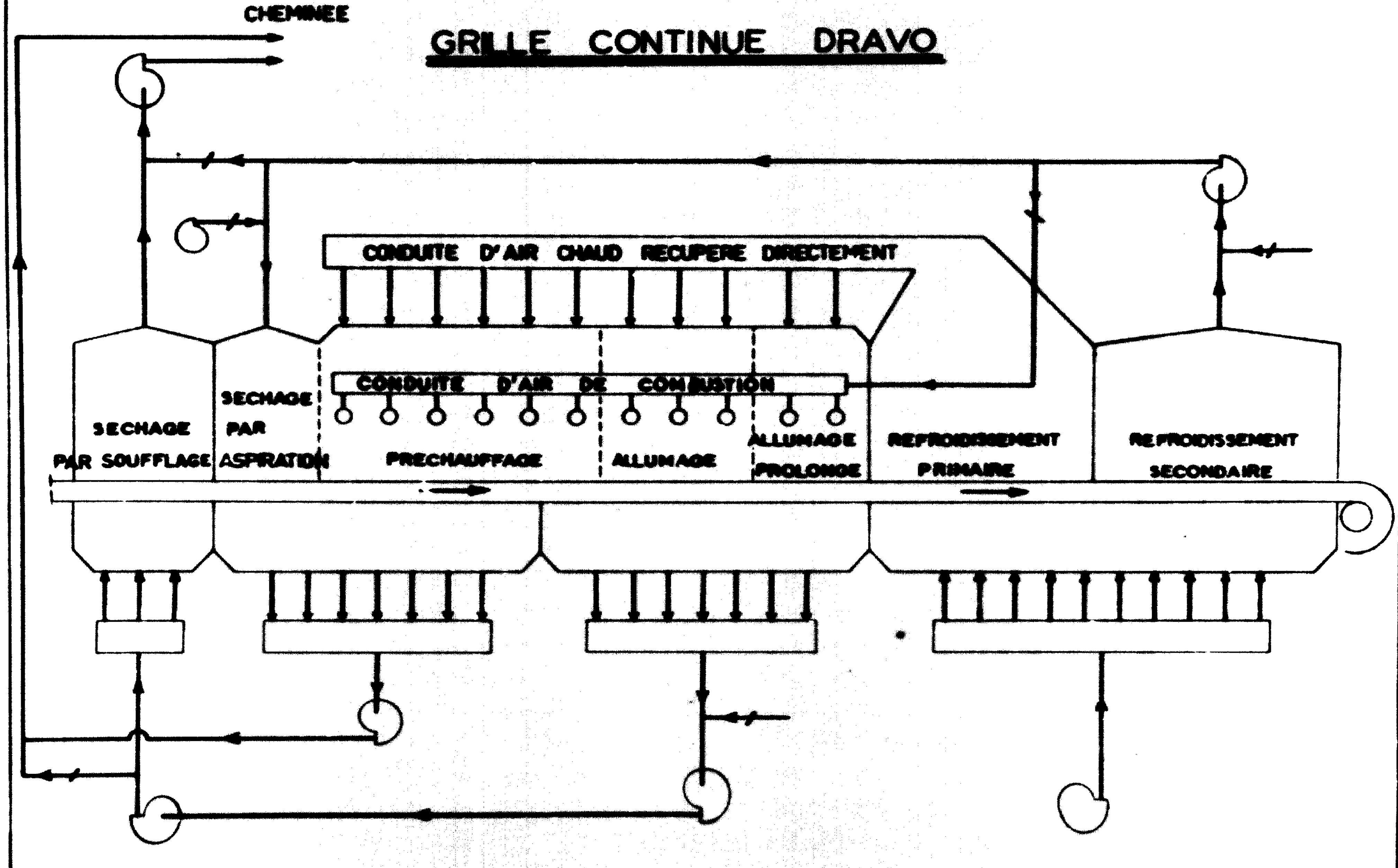
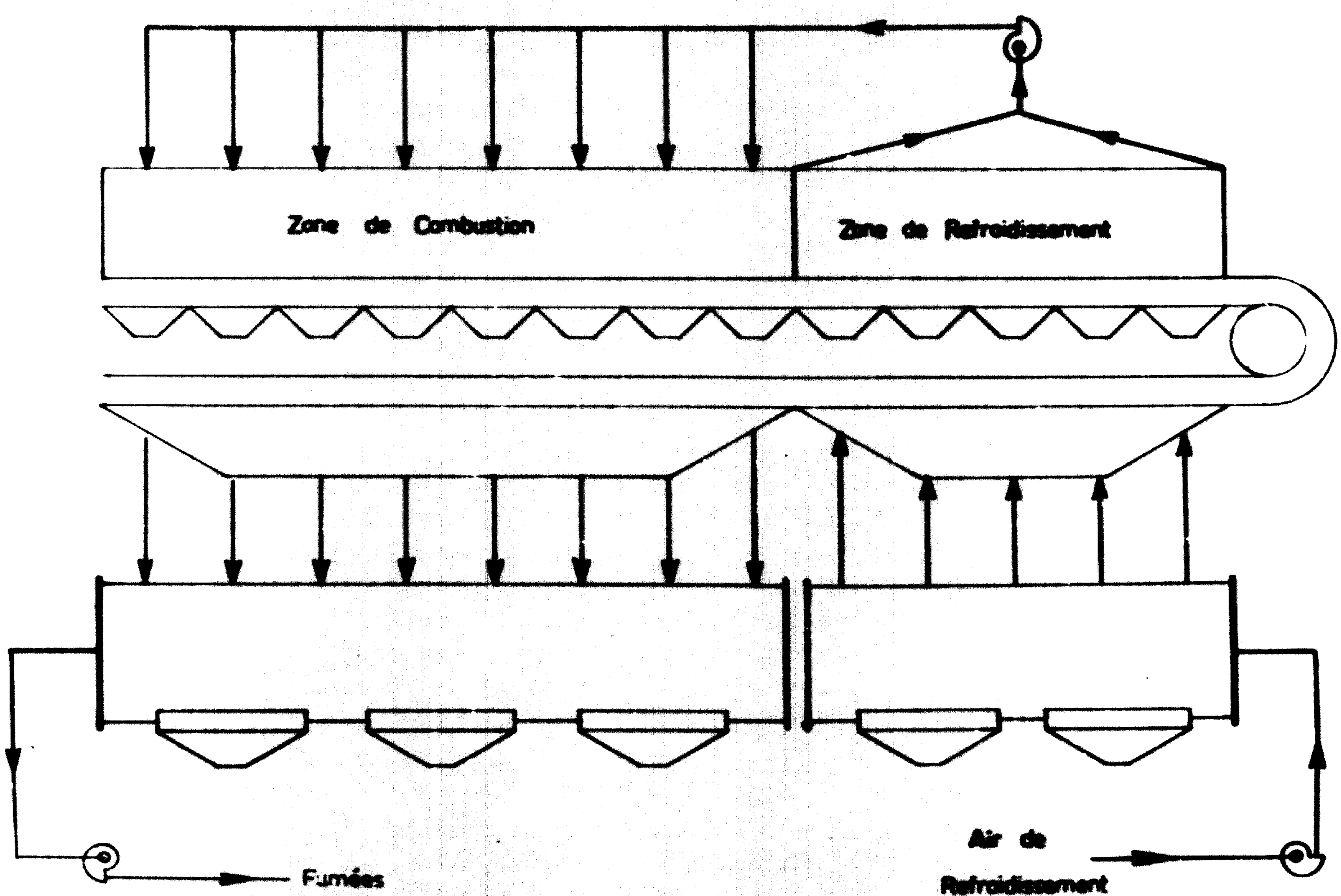


Figure 8bis

GRILLE CONTINUE LURGI



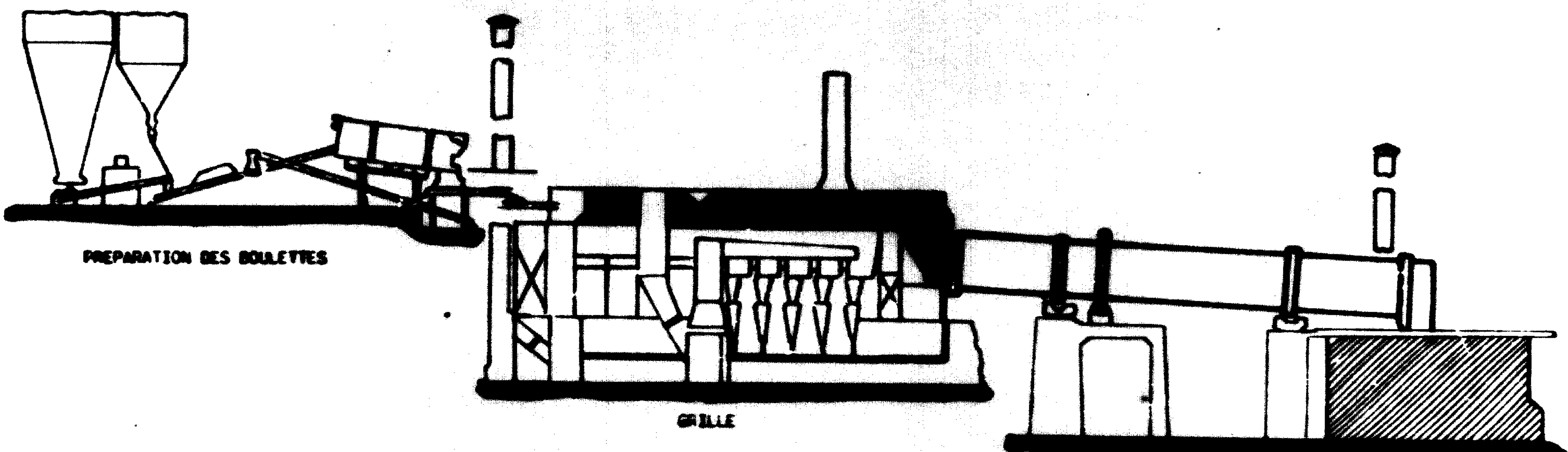


FIGURE 9 : Schéma d'un four "Grate-Kiln".

- loss in weight leading to a saving in transportation costs specially if the pellets have to be exported a long way,

- preparation of the next metallurgical operation where these is always a reduction step, either in blast furnace, in electric furnace or in any so called "direct reduction" processes,

- possible lowering of heat hardening temperature as iron crystals can form and bond grains at lower temperatures than hematite.

On the other hand, it is probably not possible to use any kind of furnaces to produce prereduced pellets and this may lead to a lower production of a given unit, compared to production of normal pellets.

Anyhow, a number of researches have been started in this filed in USSR, Australia, etc. and we shall mention recent work performed in the UNITED STATES by the BUREAU OF MINES at Minneapolis (9) or at the MICHIGAN COLLEGE OF MINING & TECHNOLOGY (10).

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2. ACTUAL DEVELOPMENT OF THE PELLETIZING PROCESSES

For the time being, the development of the different pelletizing processes can be described in considering, for each method :

- the type of raw materials used i.e. :

  a) magnetite concentrates

  b) hematite concentrates

  c) goethite, limonite or even siderite concentrates or fines

- the size of the plant and of the individual units.

We shall use, as basis for the classification the type of raw materials and we shall consider in each case, the processes which are used and the capacities of the plant.

a) AGGLOMERATION OF MAGNETITE CONCENTRATES -

The three processes we have already mentionned can be used to produce pellets and we are giving in table II essential datas compared with similar datas for sintering (in continuous strands or pars) or nodulizing in rotary kiln. Table III gives a list of commercial pelletizing plants in operation or being built. From these datas it is clear that :

- pelletizing can be applied and has actually been used for capacities ranging from a few t/day for pilot plant, to 40 t/day up to 1 000 t/day and per unit for commercial shaft furnaces and up to 5 000 or 6 000 t/day for commercial strands or GRATE-KILN units,

- thermal balance is always good with a consumption ranging down to 6 kg of fuel, i.e. around 60 thermies per ton of pellets.

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TABLEAU II - AGGLOMERATION DE CONCENTRES DE MAGNETITE -

Procédé considéré	Consommation thermique moyenne en thermies par tonne d'agglomérés	Production moyenne des unités usuelles en tonnes par jou	Référence
Agglomération sur grille	450 thermies	1 400 à 1 700 t/j pour une chaîne continue de 53 m2	Extaco, Oliver Iron Mining Div. de US STEEL - Etats-Unis
	300/325 thermies	environ 3 000 t/j pour un Greensmalt à 8 bacs soit de 20 à 30 t/m2 x j	Domnarvet, Stora Kopparberg Suède
Agglomération au four tournant	450 thermies	1 450 t pour un four de 106 m de longueur et 850 m3	Extaco, Oliver Mining Div. de US STEEL - Etats-Unis
Cuisson de boulettes au four à cuve	125/150 thermies	env. 1 000 t/j et par four	Unité de Erie Mining - Etats-Unis
	60/90 [illegible]	env. 650 t/j pour un four double	Unité de Malmberget - Suède
	90 [illegible]	env. 120 t/j	Unité de Segré - France
Cuisson de boulettes sur grille	175 [illegible]	2 500/3 000 t/j par chaîne continue de 94 m2 soit de 25 à 30 t/m2 x j	Reserve Mining (6 premières machines) Etats-Unis
Cuisson de boulettes au four Grate-Kiln	prévision envi[illegible] 150 [illegible]	prévision : 1 unité de 3 000 t/j 1 unité de 4 500 t/j	Prévision pour machines en construction

[illegible] E A U III - CAPACITE ACTUELLE (en service ou en construction) DES INSTALLATIONS D'AGGLOMERATION EN BOULETTES DE CONCENTR2S DE MAGNETITE -

a/ FOURS A CUVE

[illegible] basés sur des fours de faible capacité (40 à 250 t/j)

[illegible] ou mine	Société	Tambours de bouletage diamètre x long.	[illegible] et dimensions des fours (section)		Capacité t/j	t/an
[illegible]AS ([illegible]de) 1952	Sandvikens Jernwerks	1,2 x 5	un à 3 cuves de 1,2 x 1,05 m	3,8 m2	11	36 000
[illegible]DERFORS (Suède) 1952	Stora Kopparbergs Bergslags AB	1,2 x 5	diamètre 1,6 m	[illegible] m2	40	13 000
HELLEFORS (Suède) 1953	Hellefors Bruks AB	1,2 x 5	diamètre 2,2 m	3,8 m2	100	35 000
PERSBERG (Suède) 1954	Uddeholms AB	1,2 x 5	1,3 x 2,7 m	3,5 m2	100	35 000
FALUN (Suède)	Stora Kopparbergs	1,8 x 5	diamètre 2,8 m	6,2 m2	150	50 000
HOFORS (Suède) 1955	S K F	1,8 x 5	un à 2 cuves de 1 x 2,5 m	5 m2	150	50 000
OTANMAKI (Finlande)	Otanmäki Oy	1,8 x 5	diamètre 2,8 m	6,2 m2	250	85 000
SEGRE (France) 1961	Forges et Aciéries du Nord et de l'Est	1 de 1,2 x 3,5 1 de 1,8 x 5	diamètre 2,2 m	3,8 m2	[illegible]0	40 000

Ateliers basés sur des fours de moyenne capacité (environ 500 t/j)

Usine ou mine	Société	Equipement de l'atelier	Capacité t/j	Capacité Mt/an
STRASSA (Suède) 1963	Grängesberg	1 four double de 11 m2	800	0,280
MALMBERGET (Suède) 1955 et 1960	L K A B	2 fours doubles de 11 m2 chacun	1 300	0,450
MARMORA (Canada) 1955	Bethlehem Steel	4 fours de 6,5 m2	1 500	0,500

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TABLEAU III (suite)

Ateliers basés sur des fours de capacité de l'ordre de 1 000 t/j.

[illegible]	[illegible]	[illegible]	Capacité t/j	Capacité Mt/an
[illegible] (Etats-Unis) [illegible]	[illegible] Steel	[illegible] fours de [illegible] m2 (et [illegible] fours plus [illegible])	1 000	0,350
HILTON (Québec) 1958	Stelco et Bristol Québec Mining	5 fours de 6,0 m2	2 500	0,800
HOYT LAKES (Etats-Unis) 1959	Erie Mining	25 fours de 9,3 m2	25 000	8,300
MORGANTOWN (Etats-Unis) 1961	Bethlehem Steel	6 fours de 9,15 m2	5 400	2,000
MOOSE MOUNTAIN (Canada) 1963	National Steel	2 fours de 9,3 m2	1 800	0,600
PEA RIDGE (Etats-Unis) 1963	Meramec Mining	6 fours de 9,15 m2	5 400	2,000

B/ CHAINES [illegible]

Atelier	Société	Composition de l'atelier	Capacité t/j	Capacité Mt/an
SUDBURY (Ontario-Canada) 1960 " 1962	International Nickel "	1 chaîne Lurgi de 120 m2 1 chaîne Dravo-Lurgi de 160 m2	750 1 500	0,250 0,500
RESERVE MINING (Silver Bay - E.U.) 1956 " 1962	Armco Steel et Republic Steel "	4 chaînes A.G. McKee de 94 m2 2 chaînes A.G. McKee de 172 m2	18 000 11 700	6,000 4,000
ATLANTIC-CITY (E.U.) 1962	U.S. Steel	2 chaînes A.G. McKee de 94 m2	5 000	1,750
MARCONA (Pérou) 1963	Utah Constr.	1 chaîne Lurgi de 125 m2	3,000	1,000
MO I RANA (Norvège) 1963	Norsk Jernwerk	1 chaîne Huntington Heberlein de 145 m2	2 000	0,650
KIRUNA (Suède) 1963	L K A B	1 chaîne Head-Wrightson-McKee de 172 m2	4 500	1,500
FOLLONICA (Italie) 1963	Montecatini	1 chaîne Head-Wrightson-McKee de 50 m2	1 000	0,330

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TABLEAU III (fin)

c/ FOUR GRATE-KILN

Atelier	Société	Composition de l'atelier	Capacité t/j	Capacité Mt/an
EMPIRE, PALMER Michigan pour fin 1963	Cleveland Cliffs Iron Co	1 chaîne de 108 m2 1 four tournant de 35 m	4 500	1,400
ADAMS MINE Kirkland Lake Canada pour fin 1964	Jones and Laughlin Steel	1 chaîne de 57 m2 1 four tournant de 35 m	3 000	1,000

b) AGGLOMERATION OF HEMATITES OR OF A MIXTURE OF MAGNETITE AND HEMATITE CONCENTRATES -

A number of tests have been made to fire green pellets of hematite in shaft furnaces, like in England, in Italy, in Sweden, but this has not yet been made, up to now, on a large scale. It there are a number of difficulties in heat transfer of the necessary quantity of heat as well as a problem of recrystallisation of hematite to bond the grains and produce strong pellets and these problems look more difficult to solve in a shaft furnace, at temperatures near the softening point of the constituents of the balls.

So we are left with the two other processes we described previously i.e. heat hardening on a straight grate or in a grate-kiln system. As we did for magnetite concentrates, table IV gives the more important datas about agglomeration of hematite concentrates and table V gives a list of commercial pelletizing plants in operation or being built.

There again we see a benefit in thermal consumption compared to classical sintering plants.

c) AGGLOMERATION OF GOETHITE, LIMONITE, SIDERITE AND OTHER IRON MINERALS -

Up to now, such iron minerals have not been used in commercial pelletizing plants but, as a number of research are currently being conducted in this field, possible developments can be anticipated.

As we mentionned for pelletizing of hematite, the use of shaft furnaces for firing green pellets of limonites or siderites is still more difficult. A number of tests have been made in Germany (18) (19), France (20), England, etc. but they were conducted at a small scale and the results were not too conclusive.

A number of tests have also been made in firing the pellets on a straight grate specially by companies building such machines but we want to emphasize the use of the LEPOL or GRATE KILN process for such an application. We want, especially, to mention research at pilot plant stage (15 to 30 t pellets/day) made in our Institute (IRSID) at the Maizières-les-Metz Experimental Station. They have been conducted on concentrates or natural fines from Lorraine minette ores and lead to self fluxing pellets with iron contents between 40 and 50 %.

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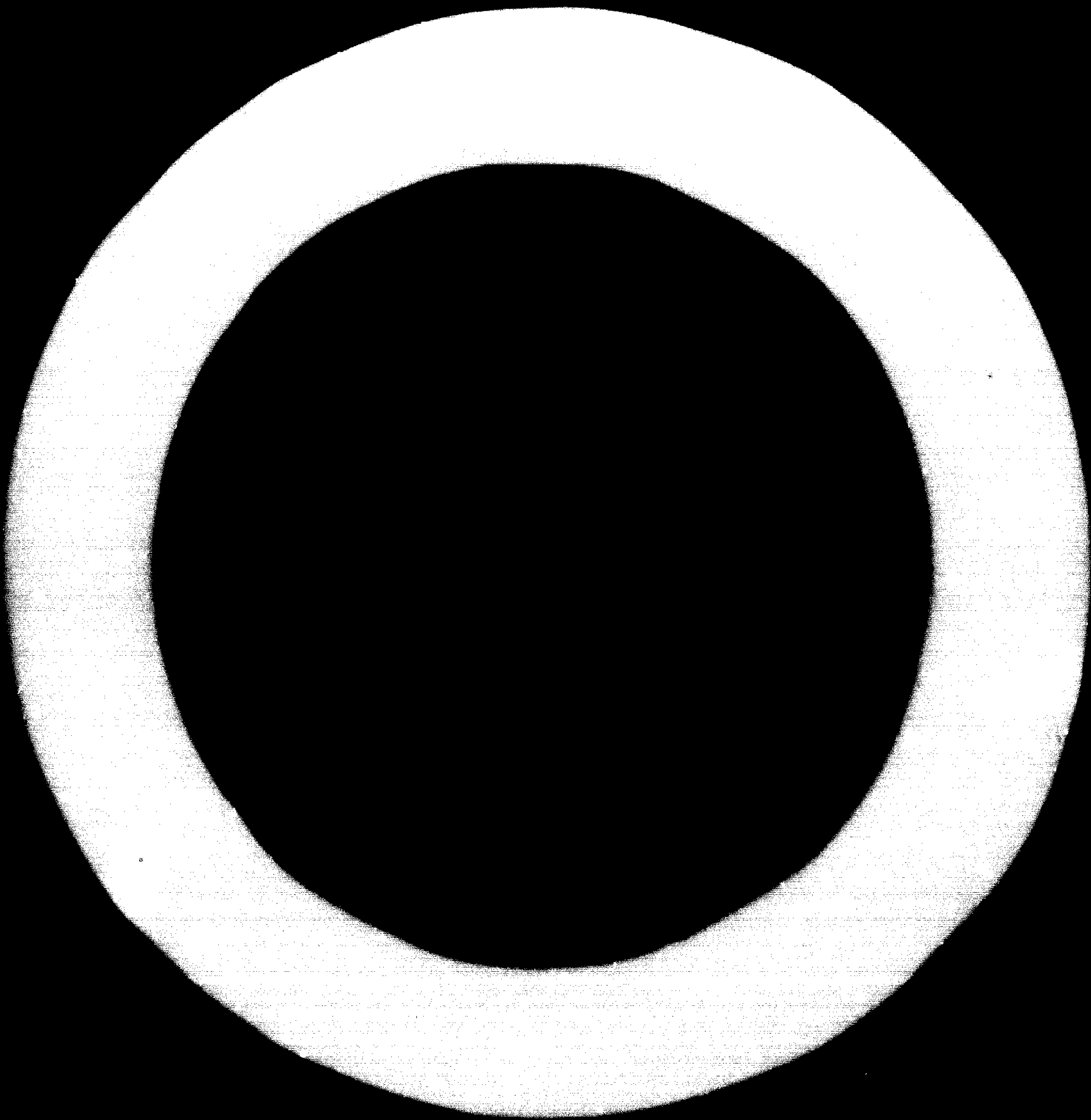

TABLEAU IV - AGGLOMÉRATION DES CONCENTRÉS D'HÉMATITE (OU DE MÉLANGE HÉMATITE-MAGNÉTITE)

Procédé considéré	Consommation thermique moyenne en thermies par tonne d'agglomérés	Production moyenne des unités usuelles en tonnes par jour	Référence
Agglomération sur grille	de l'ordre de 500 thermies	de 20 à 30 t/m2 x j	expérience industrielle
Cuisson de boulettes au four à cuve	environ 300/400 thermies	unités de 10 à 100 t/j	essais semi-industriels et industriels
Cuisson de boulettes sur grille	prévision environ 250/300 thermies	prévisions de 4 000 t/j pour environ 20 t/m2 x j	prévision pour machines entrant en service actuellement
Cuisson de boulettes au four Grate-Kiln	2-0 thermies	unités en service de 1 000 t/j et 2 500 t/j	Mines Humboldt et Republic

TABLEAU V - CAPACITE ACTUELLE (EN SERVICE OU EN CONSTRUCTION) DES INSTALLATIONS D'AGGLOMERATION EN BOULETTES DE CONCENTRES D'HEMATITE (OU EN MELANGES HEMATITE-MAGNETITE) -

a/ FOURS A CUVE

Usine ou mine	Société	Tambours de bouletage	Nombre et dimensions des fours	Capacité t/j	Capacité Mt/an
Oskarshamn (Suède)	Reymersholms Gamla Industri AB	tronconique	-	100	30 000
Ile d'Elbe (Italie)	Ferromin	2,5 m x 5 m	1 de 2 m de diamètre soit une section de 3,1 m2	100	30 000

b/ CHAINES CONTINUES

Atelier	Société	Composition de l'atelier	Capacité t/j	Capacité Mt/an
Eagle Mills	Cleveland Cliffs	1 chaîne McDowel de 129 m2	2 300	0,75
Groveland	Hanna Mining	1 chaîne Dravo de 204 m2	3 800	1,25
Carol Lake	Carol Pellets	4 chaînes Dravo de 204 m2	16 000	5,50
Pointe Noire	Wabush Mine	4 chaînes Dravo en construction	15 200	5

c/ FOUR GRATE KILN

Atelier	Société	Equipement de l'atelier	Capacité t/j	Capacité Mt/an
Humboldt-Mine Michigan, E.U.	Humboldt Mining Co	2 chaînes de 48 m2 (2,85 x 21,6) 2 fours tournants de 3,05 Ø x 36,6	2 000	0,70
Republic Mine Michigan, E.U.	Marquette Iron Ore Co	2 chaînes de 125 m2 (3,75 x 38,5) 2 fours tournants de 4,57 Ø x 34,7	5 000	1,75

TABLEAU VI - TENEURS COMPAREES DE QUELQUES TYPES DE BOULETTES -

		MALMBERGET	CAROL	RESERVE MINING
Fe	%	68,6	65,9	63,3
SiO_2	%	0,6	4,7	8,0
Al_2O_3	%	0,35	0,4	0,5
CaO	%	0,5	0,2	0,5
MgO	%	0,3	0,25	0,6
$\frac{CaO + MgO}{SiO_2 + Al_2O_3}$	%	0,84	0,09	0,13
$SiO_2 + Al_2O_3$	%	0,95	5,1	8,5
CaO + MgO	%	0,8	0,45	1,1
Référence		Malmexport AB Stockholm	M.A. Hanna Mining Co	Agglomération Symposium International 12-14 Avril 1961 à Philadelphie

TABLEAU VIII - REPARTITION ACTUELLE DE LA CAPACITE MONDIALE D'AGGLOMERATION EN BOULETTES

Types de matières premières	Capacité en millions de tonnes par an				REMARQUES
	procédé de cuisson au four à cuve	procédé de cuisson sur grille	procédé de cuisson au four Lepol (Grate Kiln)	Capacité totale	
Concentrés de magnétite	14 Mt en 1963 15 Mt en 1964	12,5 Mt en 1963 16 Mt en 1964	- 4 Mt en 1964	26,5 Mt en 1963 34,4 Mt en 1964	Etats-Unis 22,4 Mt en 1963 passant à 25,8 Mt en 1964 Canada 2,65 Mt en 1963 passant à 3,65 Mt en 1964 Suède 1 Mt en 1963 passant à 2,5 Mt en 1964
Concentrés de magnétite et d'hématite		3,75 Mt en 1963 11,75 Mt en 1965	-	3,75 Mt en 1963 11,75 Mt en 1965	dont 10,5 Mt dans les deux ateliers canadiens de Carol et Wabush
Concentrés d'hématite	au total de l'ordre de 0,100 Mt	0,75 Mt en 1963	2,5 Mt en 1963	3,25 Mt en 1963	entièrement aux Etats-Unis (Michigan)

More generally, production of self fluxing pellets or, even, basic pellets is being tried in many places using all types of furnaces. We must emphasize the point that this problem is very different when we start of a very rich and pure concentrate such as the Malmberget concentrate (see table VI) or a more siliceous concentrate such as taconite concentrates.

To summarize, table VII gives actual distribution of capacity according to :

- **the type of concentrate**
- **the pelletising process.**

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3. ECONOMICAL DATAS ABOUT PELLETIZING PROCESSES

It is now possible to have a large set of technical and economical datas abou pelletizing of iron ores due to the important number of commercial plants built since 1950 and, especially, in the last five years.

All the datas we shall quote will be related to one metric ton of pellets. Furthermore, when discussing investment costs, we shall refer to a pellet plant consisting of the balling section and the firing machine with necessary building and mechanical or electrical apparatus. There will be no provision for stockpiling of raw materials or pellets except, of course, a single bin fo the feed and, eventually, one or two bins for additions (bentonite, flux, etc.

Thermal consumption :

We shall assume following values for magnetites :

- shaft furnace	125 th/t metric
- continuous stand	175 "
- Grate-Kiln (LEPOL)	175 "

and for hematites :

- continuous strand	250 th/t metric
- Grate Kiln (LEPOL)	250 "

All this heat can be supplied by burner with gas or liquid fuels.

...

Electrical energy :

We shall assume it is independent of the raw materials with the following values :

- shaft furnace	30 kWh
- continuous strand	25 "
- Grate Kiln (LEPOL)	20 "

Fabrication costs :

They are essentially dependent of the capacity and we shall give values :

- **for different shaft furnaces at table VIII**
- **for different continuous strands or grate kiln (LEPOL) at table IX**

Investment costs :

As they vary according to the type of process and to the raw materials used, we shall give :

- **values of table X for shaft furnaces using magnetite ores,**
- **values of table XI for continuous heat hardening strands or grate kiln using magnetite ores and values of table XII for the same processes using hematite ores.**

These values have be translated by curves on figure 10 and this explains assumptions we made for establishing these datas i.e. :

- **increase of cost of the pelletizing plant as a power 0.6 of the capacity when we are increasing the size of a given unit,**

- increase of cost of the pelletizing plant as a power 0.95 of the capacity when we are adding identical units.

This way of calculation is certainly not exactly right but, in our opinion, can be used as a guide for our comparisons.

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TABLEAU VIII - FRAIS DE FABRICATION POUR DES ATELIERS EQUIPES DE FOURS A CUVE -

t/j	main d'oeuvre de fabrication			Entretien
	par poste	total par jour (3 postes + personnel de jour)	soit h/t de boulettes	F/t de boulettes
100	2	7	0,56	2,50
500	3	10	0,40	2,50
1000	5	20	0,20	2
2000	8	30	0,12	2
5000	15	55	0,09	1,50
10000	30	100	0,08	1,50
25000	50	165	0,058	1,50

TABLEAU IX - FRAIS DE FABRICATION POUR DES ATELIERS EQUIPES DE GRILLES CONTINUES OU DE FOURS GRATE-KILN -

t/j	main-d'oeuvre de fabrication			Entretien F/t de boulettes
	par poste	total par jour (3 postes + personnel de jour)	soit Heures/t de boulettes	
100	3	12	0,96	3,50
500	3	12	0,19	3
1 000	5	20	0,16	2,50
2 000	6	25	0,09	2,50
5 000	6	25	0,04	2
10 000	11	40	0,032	2
25 000	2[illegible]		0,027	1,50

TABLEAU X - ESTIMATION DES COUTS DES ATELIERS D'AGGLOMERATION EN BOULETTES EQUIPES DE FOURS A CUVE -

Capacité de l'atelier		Coût de l'atelier		Consistance de l'atelier
t/jour	1 000 t/an	par tonne/an de boulettes F	Total MF	
100	35	88	3,1	1 four
500	175	47	8,3	1 "
1 000	350	35	12,3	1 "
2 000	700	35	24,5	2 "
5 000	1 750	34	59,0	5 "
10 000	3 500	33	115,0	10 "
25 000	8 750	32	280,0	25 "

INTRODUCTION

The pelletizing process of agglomeration of iron ores or concentrates is beginning to be used on a large scale as, although it was really non-existent in 1953, it accounts for about 22 millions metric tons in 1962 on a world total production of agglomerated material (sinter, pellets, nodules, briquets, etc.) around 260 millions tons, i.e. 8,5 % as it is indicated on figure 1 (1). As far as we can foresee, a large development can be anticipated as well for small mines or plants as for large units.

We can define this process as a method of agglomeration in two steps :

- first, balling of concentrates or fine ore to produce the green pellets,

- then firing or heat hardening of the green pellets to get a strong product.

This is rather similar to some older processes, as Gröndal process (2) and also to some new research directed towards firing of "compacts" or "briquets" which are not produced by the balling technic. We shall refer briefly later to these possibilities in the first part of the paper which is devoted to the description of the different pelletizing processes. Figure 2 gives a schematic description of pelletizing compared to the Gröndal process and to sintering and hot briquetting.

The second part of the paper is devoted to the actual development of the pelletizing process and the third part covers economical considerations. The fourth part of the paper will summarize the use of pellets.

The fifth and last part is a review of possible application of the pelletizing processes to underdevelopped areas.

...

TABLEAU XI - ESTIMATION DES COUTS D'ATELIERS D'AGGLOMERATION EN BOULETTES EQUIPES DE CHAINES CONTINUES OU FOURS GRATE-KILN (MAGNETITES) -

Capacité de l'atelier		Coût de l'atelier		Consistance de l'atelier
t/jour	1 000 t/an	par tonne/an de boulettes $	Total 10^6 $	
100	35	126	4,4	1 unité
500	175	67	11,7	1 "
1 000	350	51	17,8	1 "
2 000	700	39	27,2	1 "
5 000	1 750	27	47,5	1 "
10 000	3 500	28,6	100,0	2 "
20 000	8 750	28	245,0	5 "

TABLEAU XII - ESTIMATION DES COUTS DES ATELIERS D'AGGLOMERATION EN BOULETTES EQUIPES DE CHAINES CONTINUES OU FOURS GRATE-KILN (HEMATITES) -

Capacité de l'atelier		Coût de l'atelier		Consistance de l'atelier
t/j	1 000 t/an	par tonne/an de boulettes F	Total MF	
100	35	143	5,0	1 unité
500	175	74	13,0	1 "
1 000	350	57	20,0	1 "
2 000	700	43	30,0	1 "
5 000	1 750	30	52,5	1 "
10 000	3 500	29	102,0	2 "
25 000	8 750	28,5	250,0	5 "

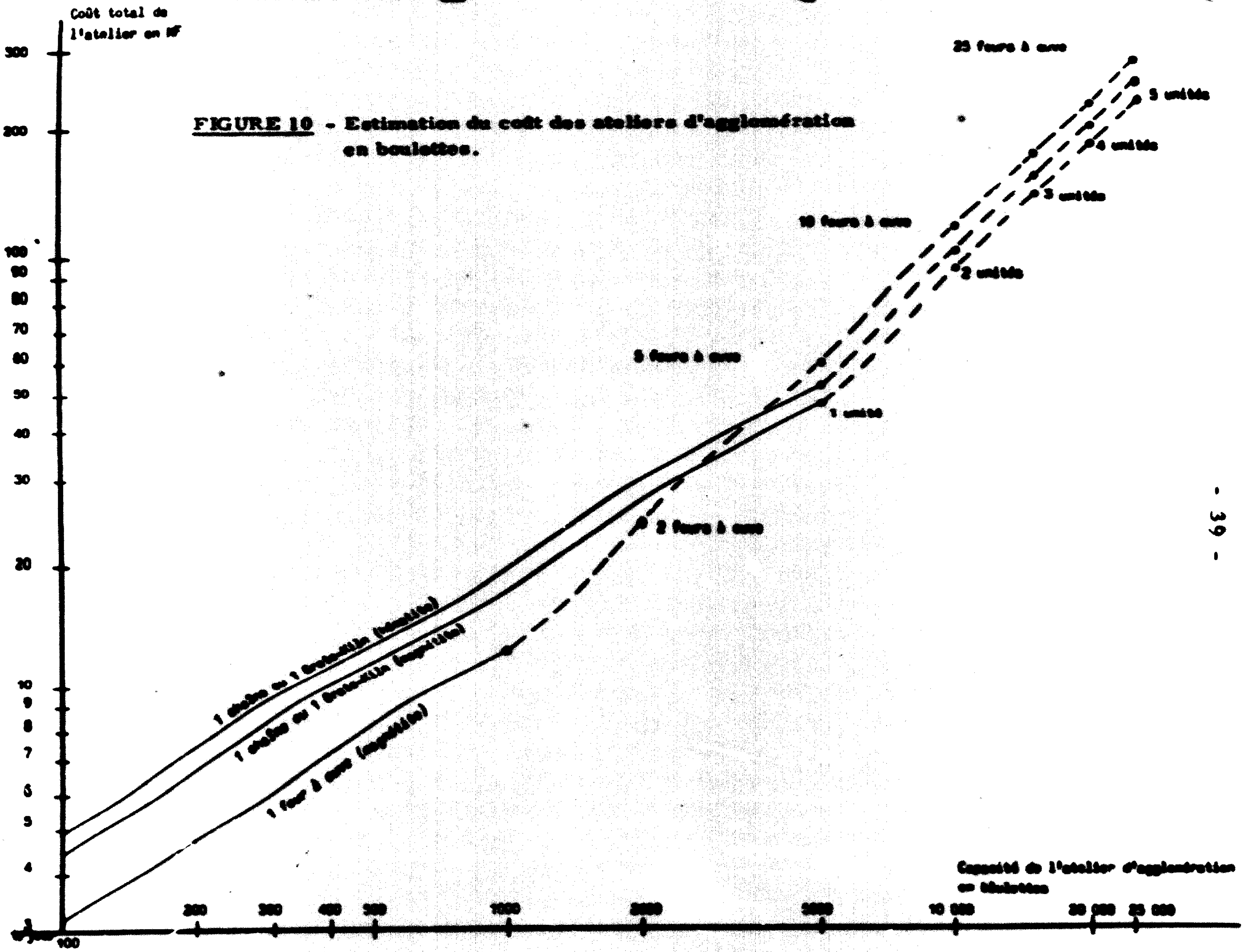

FIGURE 10 - Estimation du coût des ateliers d'agglomération en boulettes.

4. PRESENT AND FUTURE UTILIZATION OF PELLETS

The biggest part of the world production of pellets is used in blast furnaces so we shall devote the largest part of this chapter to this application but we shall also mention other interesting uses of pellets such as electrical smelting furnaces direct reduction and steelmaking.

a/ USE OF PELLETS IN BLAST FURNACES -

Advantages due to the use of pellets have been described in several cases and the spectacular results of ARMCO (11) are given, once more, at table XIII.

It must, however, be said that sinters and, especially, closely sized sinters have also led to excellent results (12) and, if the comparison between crude ore and pellets must be made in some special circumstances, the main comparison has to be made between sinter and pellets.

In that connection, published results (13) lead to a considerable dispersion and if we want to list the best known results of blast furnaces in the world (table XIV), it is difficult to reach an overall definite conclusion. So, we shall review in more details results of laboratory research as well as those from experimental blast furnace.

Laboratory research :

Numerous tests have been made in USSR, USA or in Europe and it is impossible of course to list all of them in our paper. We want, anyhow, to comment a few recent datas such as those presented by POOS and LINDER (14) at the Luxembourg meeting of 1962 or those obtained at IRSID by a special reducibility method simulating the counter-current conditions prevailing in the shaft of a blast furnace (15). All these tests show that pellets are, generally, reduced pretty fast but the operating conditions play an important part in the phenomenon and, as it could have been suspected quality of pellets and, especially, then size can modify in a large part the conclusions. In other words, results of these tests have to be used with precaution.

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TABLEAU XIII - EVOLUTION DES PERFORMANCES D'UN HAUT FOURNEAU d'ARMCO à MIDDLETOWN - Etats-Unis -

Date de l'essai		AOUT 1954	MAI 1960	NOVEMBRE 1960	JUIN 1961
Lit de fusion :					
minerai	kg/tf	1 297	-	-	-
pellets	kg/tf	325	1 487	1 451	1 540
divers (*)	kg/tf	377	274	253	215
castine	kg/tf	338	215	210	220
Indices de marche :					
Débit de vent	m3/mn	2 350	3 100	2 380	3 480
Mise au mille de coke	kg/tf	812	638	591	652
Laitier	kg/tf	562	369	367	380
Production moyenne	t/j	1 330	2 540	2 130	2 670
" ajustée	t/j	1 340	2 565	2 200	2 736

(*) scories Martin, pailles, etc.

TABLEAU XIV - QUELQUES UNES DES MEILLEURES PERFORMANCES MONDIALES DE HAUTS FOURNEAUX -

Usine	Haut fourneau diamètre creuset m	Haut fourneau volume utile m3	Type de charge	Volume de laitier kg/tf	Mise au mille de coke kg/tf	Production de fonte tf/j	Production de fonte tf/mois
Tcherepovets (URSS)	9,75	2 002	100 % sinter	585	525+35 m3 g.n.	3 520	-
Krivoï Rog (URSS)	9,75	2 002	100 % sinter autofondant	685	522 + 71 m3 g.n.	3 100	-
Broken Hill (Australie) Port Kembla	8,84		90 % sinter 10 % minerai	400	625	2 802	84 079
Bethlehem Steel Co. Bethlehem (Etats-Unis)	8,76		65 % pellets 22,5 % sinter	268	586	2 696	83 575
Armco Steel Corp. Middletown (E.U.)	8,53		88 % pellets	380	652	2 660	80 070
Youngstown Sheet and Tube Co. - Indiana Harbor (E.U.)	8,53		83 % pellets	328	611	2 427	75 224
Sud de l'URSS	9,10	1 719	90 % sinter	770	727	2 313	-
Great Lakes Steel Corp. Détroit (E.U.)	8,84		100 % pellets	307	528 + 50 m3 gaz nat.	2 289	-
Ford Motor Co Détroit (E.U.)	8,84		60 % pellets 40 % sinter			2 127	-
USINOR Dunkerque (France)	8,50	1 288	90 % sinter 10 % minerai	339	609	1 930	-
Tcherepovets (URSS)	7,00	1 033	100 % sinter autofondant	645	560	1 918	-
Phoenix Rheinrohr Duisburg (Allemagne)	7,50		55 % sinter	440	587	1 601	-
Hoesch AG Westfalenhütte (All.)	7,50		80 % sinter	361	562	1 461	-
Amagasaki (Japon)	6,00	674	100 % sinter 78 kg [illegible]	382	513	1 124	-
La Providence Rehon (France)	5,30	632	100 % sinter	1 080	609 + 37 kg fuel-oil	610	-
Kokura (Japon)	5,57	457	100 % sinter	439	548	555	-
SIDELOR	5,00	567	90 % sinter 10 % minerai	1 005	587 + 32 kg fuel-oil	470	-

Experimental blast furnaces :

A number of tests have been made in such furnaces, such as those of Liège (Belgique) or Bruceton (USA) but, there again, it is difficult to draw a final conclusion as Mr MAHAN emphasized it at his communication in Luxembourg (16). This communication gives however a number of interesting datas:

- comparing agglomerates used at Bruceton, pellets appears definitely more reducible as it is clear on table XV giving coke rate and gas analysis. This conclusion must, however, be weighed by the fact there are large variations in pellets or sinter qualities; it may be questioned, for example, if the sinters used at Bruceton could not have been improved...

- in the same conditions, pellets lead to higher hot metal production (table XVI) but, as a matter of fact, this is just a consequence of the first conclusion as the furnace was run at the same blast volume for each "pair" of test.

Industrial practice in blast furnaces :

Coming again to the results of table XIV, we can sort out the conclusions regarding coke rate and production.

As regards coke rate, figure 11 does not show any clear advantage for pellets. As a possible explanation we want to say :

- first, if some pellets are better than the average sinter, there is so much variation in quality that a definite conclusion is difficult to attain,

- next, that pellets are, actually, not self fluxing at least for the time being so, if they have some advantages in reducibility over sinters, they may lose there some of their benefit.

As regards hot metal production, figure 12 lists some of the main datas as a function of hearth diameter. There again, a formal conclusion is difficult to express as it seems a number of other factors may play a non negligible role in the comparison. If, indeed, pellets constitutes an uniform burden, screened sinters may also lead to excellent permeability of the stack column and to high production.

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TABLEAU XV - RÉSULTATS D'ESSAIS AU HAUT FOURNEAU EXPÉRIMENTAL DE BRUCETON (U.S. BUREAU OF MINES, ÉTATS-UNIS, d'après MAHAN) -

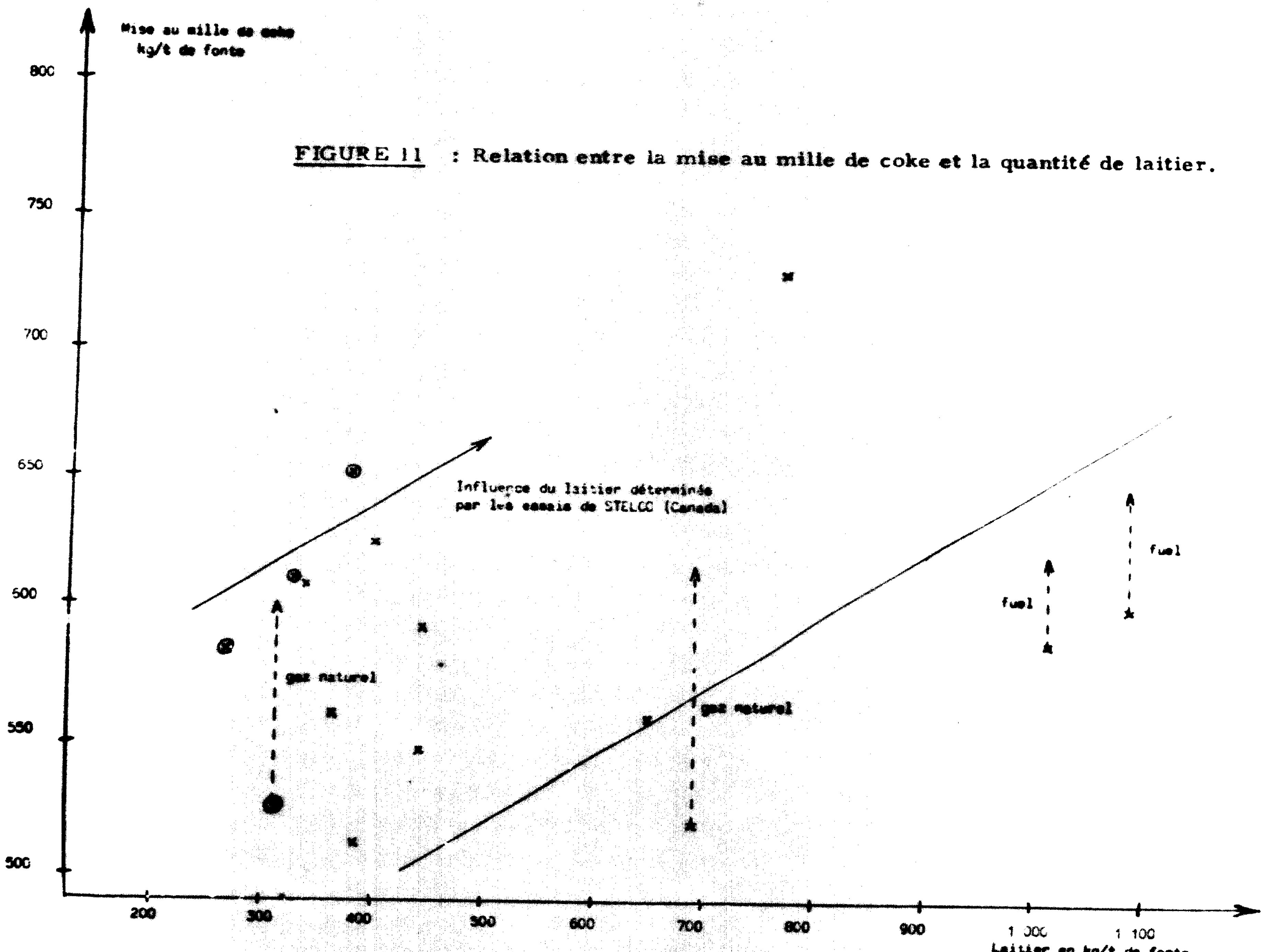
I. MISE AU MILLE DE COKE

Type de charge		100 % boulettes cuites sur grille (tirage ascendant)	100 % boulettes au procédé Grate-Kiln		100 % boulettes autofondantes	100 % agglomérés autofondants préparés sur grille	
			Essai 1	Essai 2		1	2
Gaz de gueulard	CO %	25,5	23,0	22,[illegible]	27,4	28,2	27,8
	CO_2 %	16,5	19,8	21,3	14,9	11,6	12,7
Mise au mille de coke	kg/tf	580	516	526	578	628	640
Température du vent	°C	1 360	1 360	1 360	1 260	1 360	945
Vapeur g/m3		62	63,5	64		46,5	
					20,6		16

TABLEAU XVI - RESULTATS D'ESSAIS AU HAUT FOURNEAU EXPERIMENTAL DE BRUCETON (U.S. BUREAU OF MINES, ETATS-UNIS, d'après MAHAN) -

II. PRODUCTION

Type de charge		100 % boulettes cuites sur grille (tirage ascendant)	100 % boulettes du procédé Grate-Kiln		100 % boulettes autofondantes	100 % agglomérés autofondants préparés sur grille	
			Essai 1	Essai 2		1	2
Débit de vent	Nm3/mn	21,2	21,4	21,9	37,6	21,8	37,8
Production	t/j	20,2	22,5	20,7	34,5	17,3	28,7
Allure coke	t/j	11,8	11,6	10,9	20,0	10,8	18,4



<u>FIGURE 11</u> : Relation entre la mise au mille de coke et la quantité de laitier.

1. DESCRIPTION OF THE PELLETIZING PROCESSES

As we mentionned before, the pelletizing process as a two-step process is rather similar to the old Gröndal process which was largely used in Scandinavia or in the U.S.A. figure 2 gives the schematic principle of this process. Figure 3 illustrates the difference between these two processes and we have mentionned there the different ways of briqueting or pelletizing as well as the different furnaces used for firing pellets.

HISTORICAL -

It must be said, at that point, that the first research in pelletizing are pretty old as experiments were made in Sweden by ANDERSSEN in 1912 then in Germany around 1932. The most important researches are, however, more recent : they started at the end of the last war when a suitable agglomeration process was badly needed for taconite concentrates which were beginning to be produced :

- first on laboratory scale :

  at the Mine Experiment Station in Minneapolis under the leadership of Prof. DAVIS

  at the research Station of a number of companies such as PICKANDS MATHER, BETHLEHEM STEEL, BRASSERT, etc.

- then at a pilot plant stage since 1950 :

  at AURORA for the ERIE MINING group

  at LEBANON in a semi commercial plant

  and at BABBITT for the RESERVE MINING group

- to end with the pelletizing plant of, shall we say, the <u>first generation</u> i.e. the commercial plants treating magnetite concentrates finely ground such as taconite concentrates.

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Laitier en kg/t de fonte

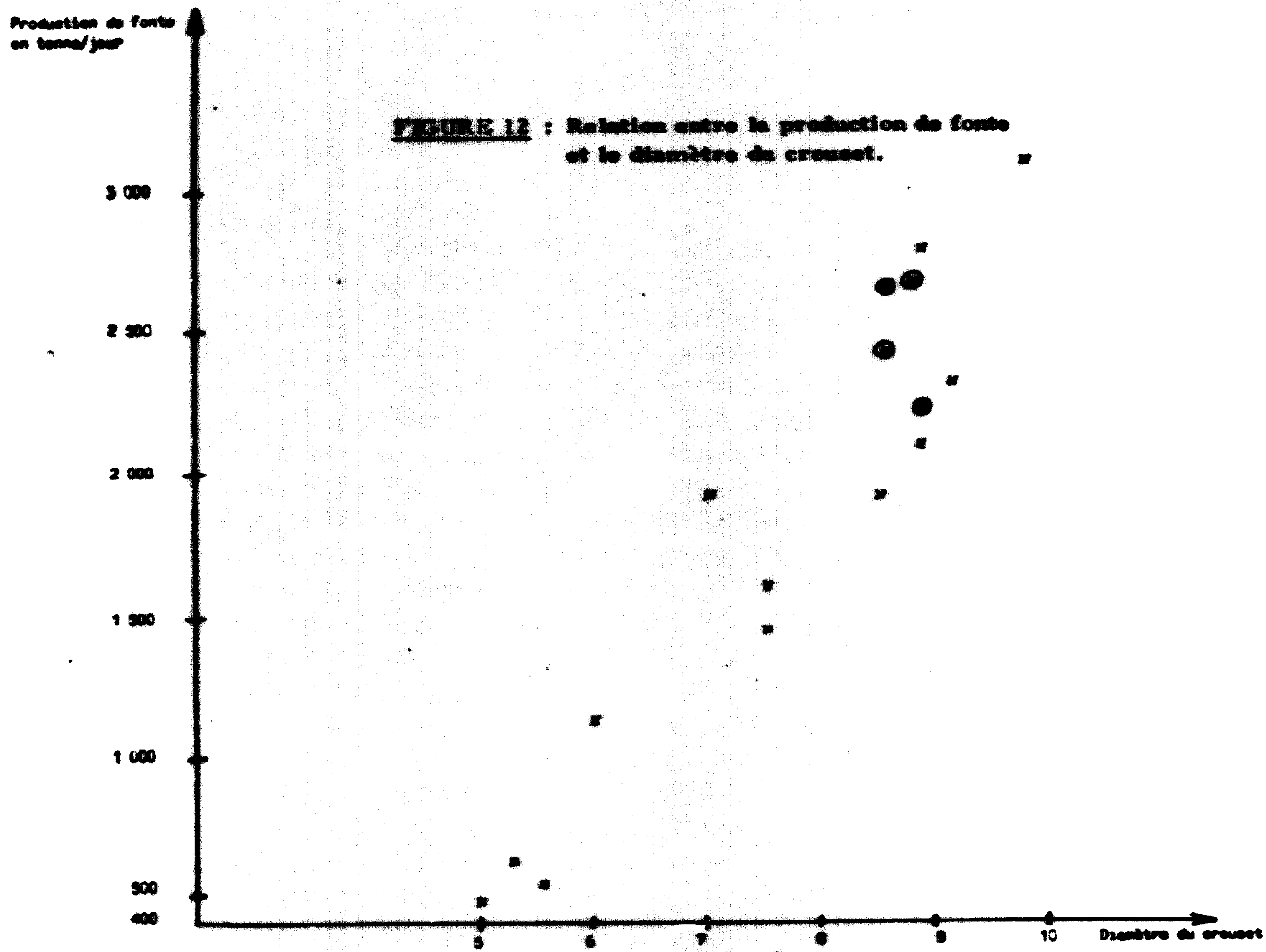

FIGURE 12 : Relation entre la production de fonte et le diamètre du creuset.

b/ USE OF PELLETS IN ELECTRIC IRONMAKING FURNACE -

This use is not yet important but it must be said that a large pelletizing plant is just being built at MO I RANA (Norway) to feed the large smelting furnaces of this plant. A number of advantages will certainly be evident when this plant will be in operation, first, all the advantages already well known when using sinters in electric furnaces and, second, the possibility of using these pellets in the preheating and prereducing shafts which are currently being tested by ELEKTROKEMISK (17).

It must also be noted that at VILA COVA (Portugal), ELEKTROKEMISK is testing the same kind of preheating shafts with green pellets, hardened by addition of a small percentage of cement.

c/ REDUCTION BY GASES -

This use is already pretty well developped as nearly all the Swedish WIBERG plants are fed with pellets; this means a tonnage of around 100 000 t of iron per year.

Examples of such schemes may be found at :

- Hellefors (21) for a capacity of 20 000 t/year of metal
- Persberg (22) from Uddeholms AB group, with a capacity of 40 000 t/year of metal
- Bodås and Sandviken (23) for 20 000 t/year each
- Hofors and Söderfors.

Figure 13 gives the scheme of such a plant and it is clear that this could be duplicated for other gas reduction processes using shaft furnaces or fixed beds such as the HyL process.

d/ REDUCTION BY SOLID CARBON IN ROTARY KILN -

The use of pellets and, even, green pellets has been suggested or tested for all processes of reduction in rotary kilns such as KRUPP in Germany, FREEMAN in Canada, etc. but we want to mention, especially :

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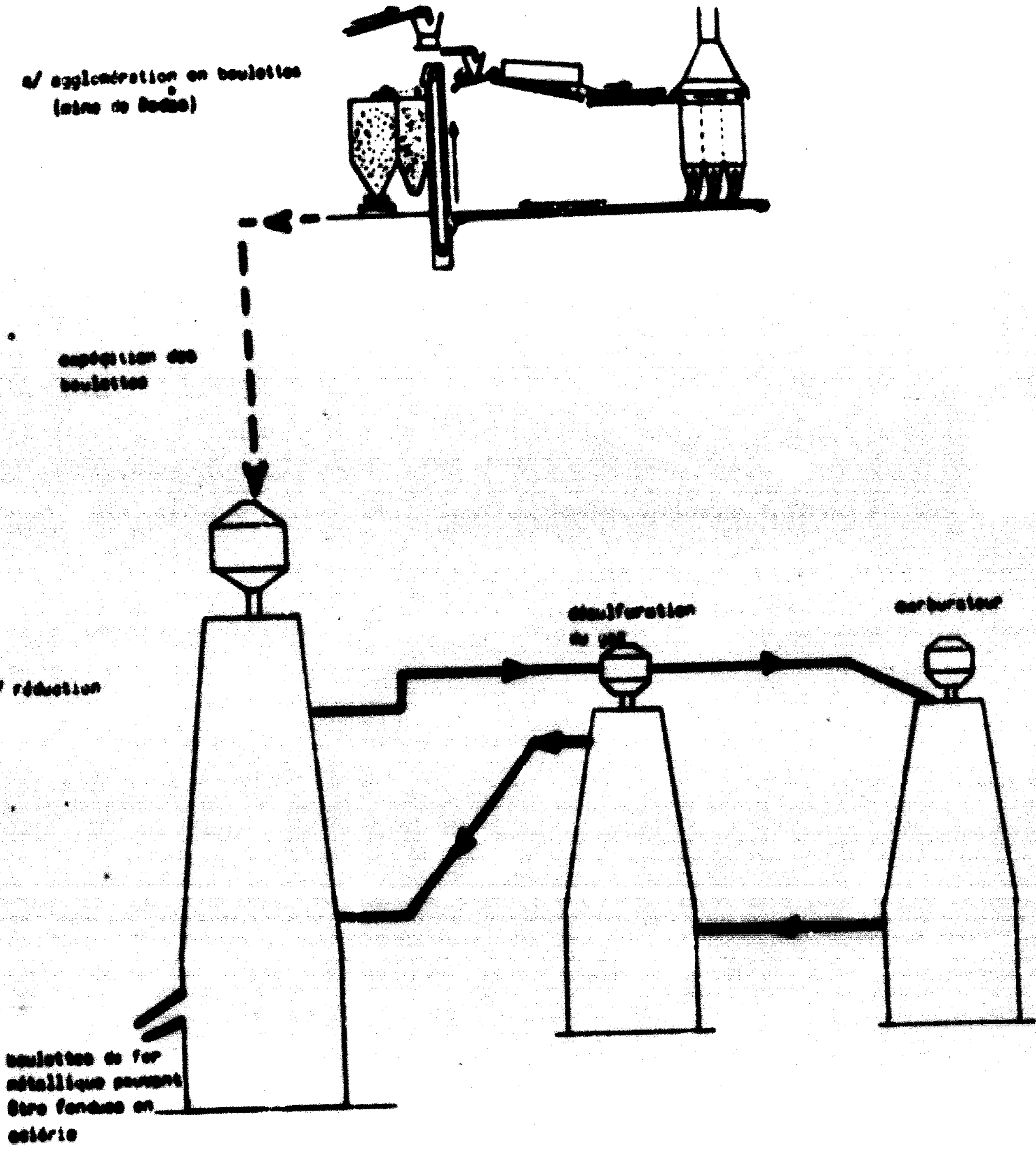

<u>FIGURE 13</u> : **Schéma de l'ensemble : agglomération en boulettes et réduction au four Wiberg (exemple de Sandviken, Subde).**

- the research and development of the RN group in the United States where the use of pellets was tested in a number of campaigns. Figure 14 gives, from BREITENSTEIN (24) a suggested industrial scheme where must be noted the use of a grate to dry and preheat the pellets;

- the pilot plant work of STELCO - LURGI for which we give at figure 15 the flow sheet published by SIBAKIN (25) (26).

e/ STEELMAKING -

There again, without elaborating in details, we want to mention a number of uses of pellets :

- in basic or even acid open hearth, especially in Sweden,

- in electric steelmaking furnaces,

- and, especially, as a cooling agent in oxygen steelmaking processes. A large part of the pellets produced at Malmberget in Sweden or in Segré in France are, indeed, used in Basic Oxygen converters or Kaldo furnaces.

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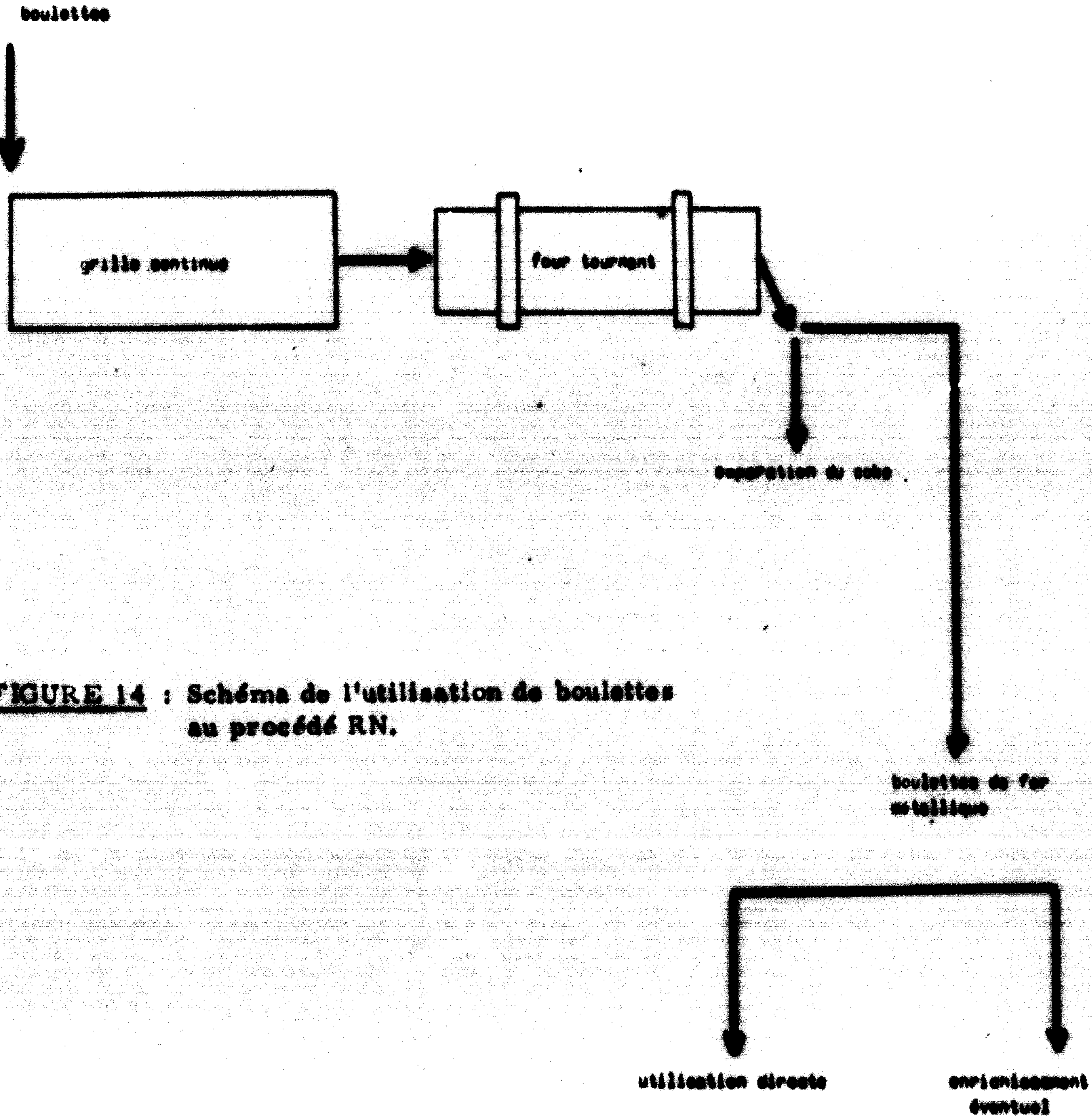

FIGURE 14 : **Schéma de l'utilisation de boulettes au procédé RN.**

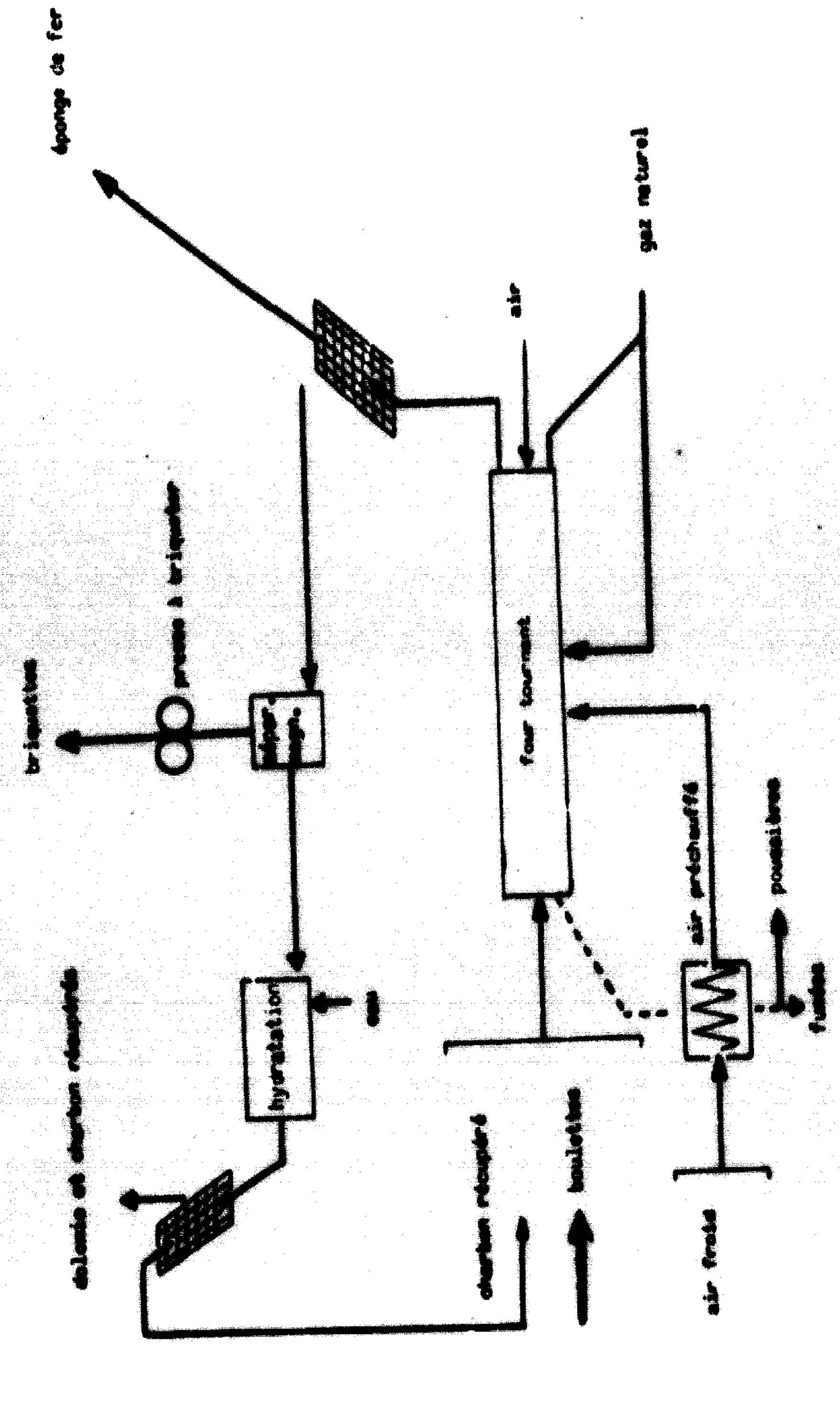

FIGURE 15 : Schéma de l'utilisation des boulettes au procédé SL.

5. POSSIBLE APPLICATION OF PELLETIZING PROCESSES TO LESSER DEVELOPPED AREAS.

As it was previously expressed (27), the main problems for these areas, as regards iron and steelmaking are :

- either to mine national mineral resources to export them in other part of the same country or abroad,

- or to use them as a basis for a local iron and steel industry.

In both programs, pelletizing can play an important part and this is due, in our opinion, to following characteristics of this process :

- possibility to use a variety of different raw materials;

- possibility to transport pellets on long distances;

- possibility to use pellets in a large number of different metallurgical schemes.

a/ Raw materials :

If a new deposit is supposed to be worked, the question of pelletizing has to be raised. As we said before, all depends of the mineralogical nature of the ore (or of the concentrates) and of the size analysis. In summarizing previous conclusions, it can be said that pelletizing is :

- quite classical operation for magnetite or hematite concentrate or fines, at least if they are ground at sufficient fineness; in many deposits, it is actually necessary to grind such ores very fine to concentrate the iron minerals so pelletizing is a logical step following beneficiation of the crude ore;

- being tested on a number of different ores such as limonite, goethites, siderites, etc.

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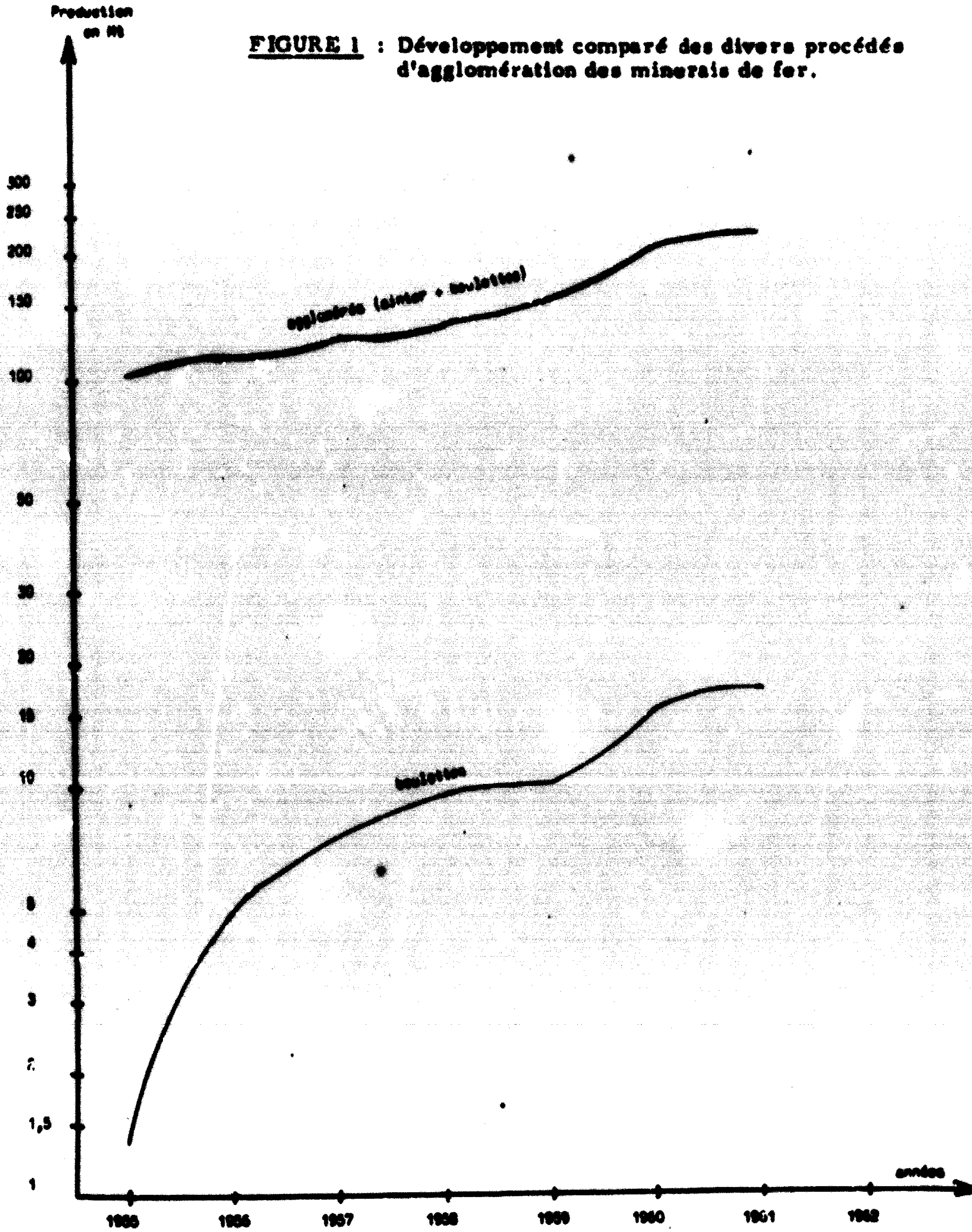
FIGURE 1 : **Développement comparé des divers procédés d'agglomération des minerais de fer.**



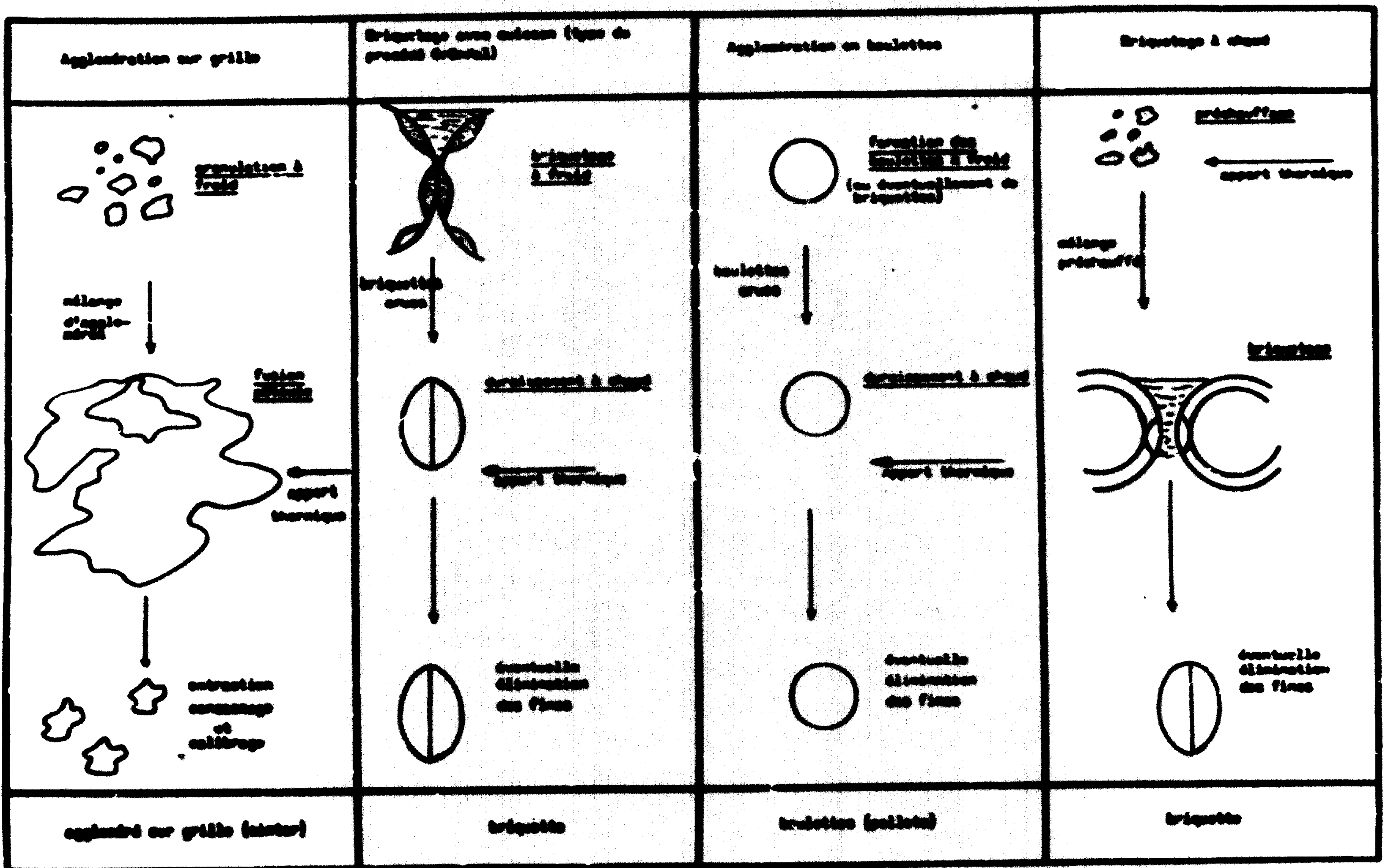


FIGURE 2 : Principe de quatre méthodes d'agglomération des minerais de fer.

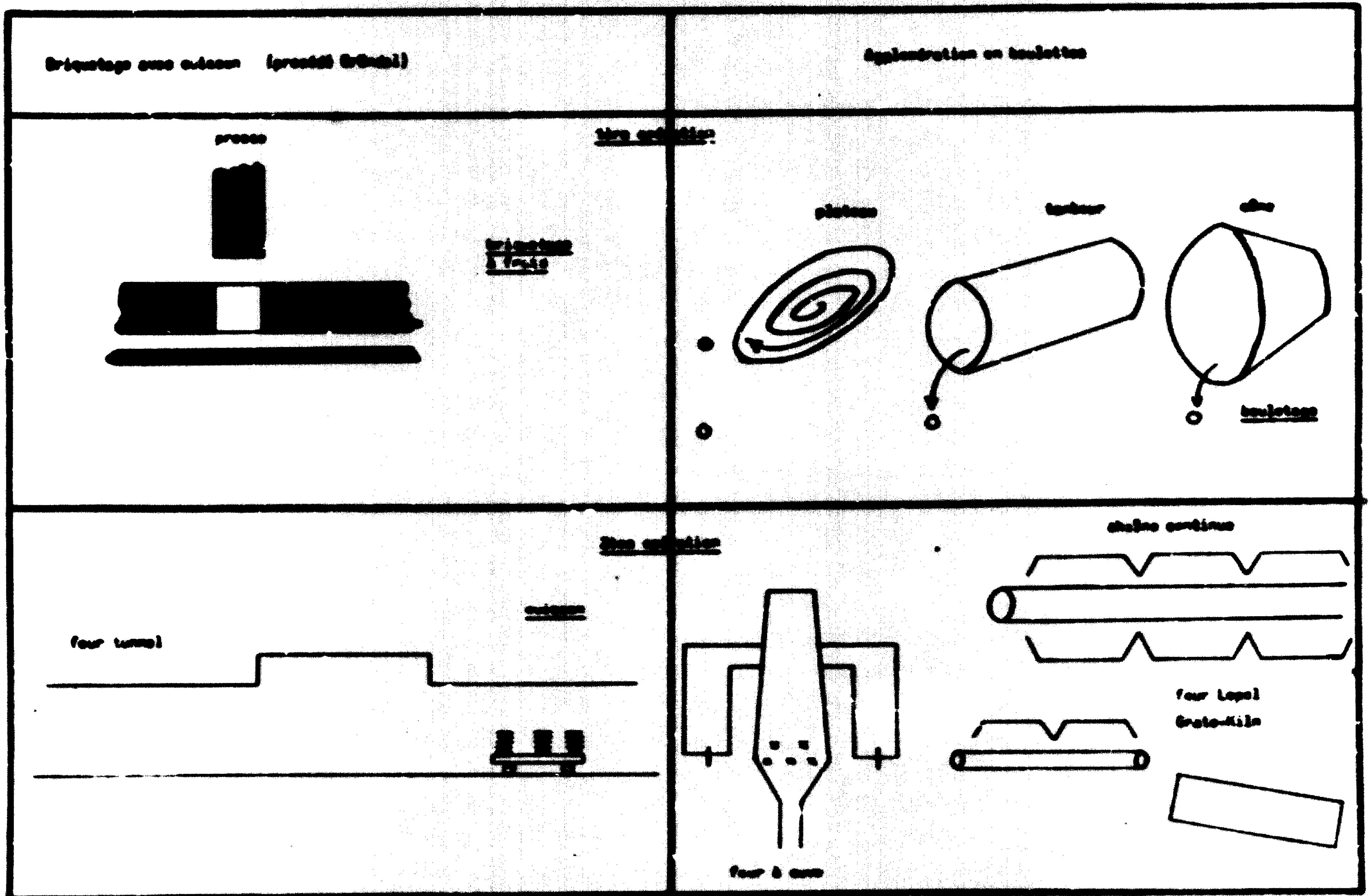


FIGURE 3 - **Comparaison des procédés de briquetage et de bouletage.**

These plants are :

- shaft furnaces units belonging to the BETHLEHEM STEEL and PICKANDS MATHER group such as :

  - LEBANON (Pennsylvania, USA) and MARMORA (Ontario, Canada) in 1955

  - HILTON (Quebec, Canada) in 1958

  and, especially the large plant of :

  - HOYT LAKE (ERIE MINING) in 1958

  with a capacity of 9 millions metric tons per year.

- heat hardening strands starting in 1956 at :

  - EAGLE MILLS for CLEVELAND CLIFFS (Michigan, U.S.A.) which was the only one at that time treating hematite concentrates and built by the McDOWELL group

  - SUDBURY for International Nickel (Ontario, Canada) built by LURGI

  - and, especially, SILVER BAY for RESERVE MINING (Minnesota, USA) built by Arthur G. McKEE with an initial capacity of 6 millions tons, increased recently to 10 millions tons.

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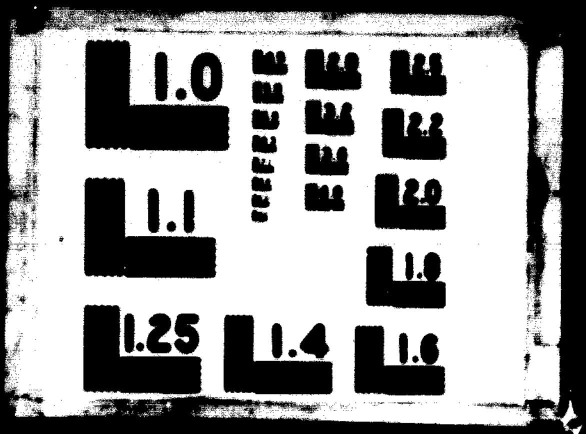

In other words, most of the world iron ore deposits will certainly in the near future, be amenable to pelletizing. It must, however, be recalled that sintering is still more flexible and can be used for any kind of fine ores without taking too much care of the mineralogical nature or of the size analysis of raw materials. Furthermore, sintering is being gradually improved and adjusted to fit more and more the different local situation. This is especially true in the way of an improvement of thermal balance of the process and of sinter quality. On the other hand, pellets show a definite advantages in ability to be transported without too much degradation.

b/ Transportation of pellets :

This is, indeed, a quite serious advantage of pellets which are, for the time being, the artifical agglomerated product easier to handle and to haul over long distances.

This point is quite clear by looking again to table III and IV and seeing the location of the pelletizing plants. All these plants are, indeed, at mine site or in the immediate vicinity; so, the pellets have to be transported over long distances par railway (Eastern part of the USA) or by boat, especially over the Lakes, or, more often, by a combination of both transportation system with accompanying handling problems.

c/ Possible iron and steel development schemes based on pellets :

If, by using a suitable iron ore deposit, pellet production looks possible, a large number of different schemes can be envisionned, at least from a technical point of view as :

- pellets can be easily transported and handled; so they may constitute a basis for export;

- pellets can be used in a large number of ironmaking or steelmaking processes; so they may be the basis for a conventional plant (i.e. using blast furnaces); or for a plant using largely electrical energy (i.e. electric smelting furnaces), or coal (i.e. rotary kilns) or even gas (WIBERG or HyL process, for example).

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TABLEAU XVII - EXEMPLE DE VARIATION DES FRAIS DE FABRICATION D'UNE TONNE DE BOULETTES -

basé sur le cas de concentrés de magnétite avec amortissement à 10 % du coût des ateliers
l'heure de main-d'oeuvre (charge comprise) à 10 F
la thermie à 0,015 F
l'énergie électrique à 0,05 F/kWh

Capacité retenue	Type d'atelier retenu	Frais de fabrication F/t de boulettes		
100	un four à cuve	20,275		
500	un four à cuve	14,575		
1 000	un four à cuve	10,975		
	une chaîne de cuisson de boulettes		13,075	
	un four Grate-Kiln			12,925
5 000	cinq fours à cuve	9,175		
	une chaîne de cuisson de boulettes		8,975	
	un four Grate-Kiln			8,725
25 000	vingt-cinq fours à cuve	8,625		
	cinq chaînes de cuisson de boulettes		8,245	
	cinq fours Grate-Kiln			7,[illegible]

By combination of all these potentialities, an iron ore deposit may be opened with building a concentration and a pelletizing plant feeding :

- a local plant aimed at providing steel products for the country,

- in the same time, an export market towards more developped countries.

Depending of the growth of these uses, the expansion of the local plant, especially, a gradual development of the pelletizing plants by adding new units, can be envisionned.

From an economical point of view, it must be said that, if the largest plant are, of course, the most profitable and lead to lower costs (as it was seen at Chapter II), small plants may be quite efficient in special locations, especially by using smaller iron ore deposits. Table XVII indicates as an example how vary total agglomeration costs when capacity increases from 100 to 25 000 t/day. Depending of location and market, building of a comparatively small pelletizing plant is certainly a definite possibility. A good proof of this fact is given by the large number of comparatinely small pelletizing plants built in Scandinavia, Italy, France, etc.

By gathering all these conclusions, it is clear that, in an area being developped, every plan to use a given iron ore deposit must take in account the possibility of pelletizing the ore.

CONCLUSIONS

In this paper, we had, of course, to simplify and to give schematic conclusions in many places. Many points could, as a consequence, be questioned but, anyhow, a number of general conclusions emerge from our survey :

- first, the pelletizing process are in constant evolution; after being restricted to the use of magnetite, then, of hematite concentrates, they begin to be used to different raw materials such as complex ores with goethite, limonite, siderite, etc.

- second, the sintering processes are still more flexible and are easier to operate with different and variable raw materials; furthermore, analysis of actual operating datas does not permit to see a definite advantage in the use of pellets VS sinter in blast furnaces;

- the main advantages of pellets are thus, in the saving of fabrication costs, especially as regards fuels, and, also, in the excellent resistance to handling and transportation of the pellets;

- so, pellets are in the same time, a good agglomerate to be used locally or to be exported.

This point must be stressed when a number of iron ore deposits are, currently, being studied to be used in the future. If the ore can be pelletized, such as concentrates from beneficiation of fine grained magnetites or hematites, a pelletizing plant may be a good starting point as well for export as for promoting a local iron and steel industry, conventional or based on a new direct reduction process.

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