are available for publication, and it does not appear to have been applied to steel refining on a commercial scale of operation.

The Soderberg Furnace is of the combined arc and resistance type, and is similar in principle and design to that of Nathusius (see p. 169). Richards, in the *Transactions of the American Electro-chemical Society*,[1] has given details of a furnace of this type which is being erected at the works of the Jossingfjord Manufacturing Company in Norway. The furnace is circular, and will hold 2·5 tons of metal. The three electrodes passing through the roof are connected to a three-phase generator by a "star" connection. Six small electrodes, each ¾ in. in diameter, are embedded in the hearth, and serve as connection to the bath. This latter acts as the neutral point of the system. Little or no current passes through these embedded electrodes; consequently the arcs from the upper electrodes pass in one direction only, namely from the electrodes to the bath, and are not in series with one another.

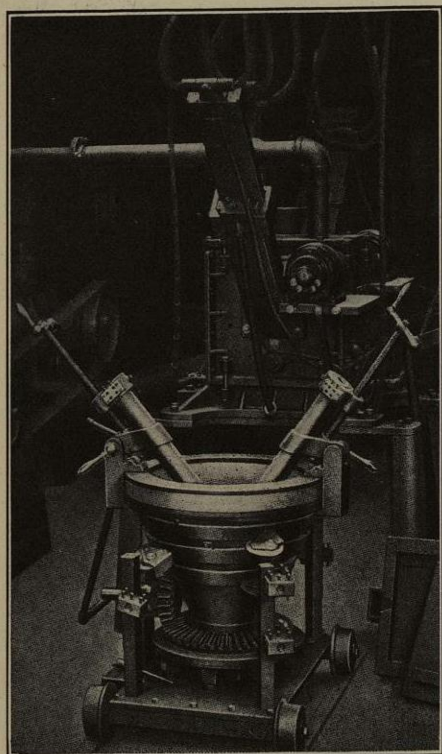

FIG. 92.—Experimental type of Reid Furnace.

[1] Vol. XX., p. 413.

CHAPTER XI

COMPARATIVE POWER CONSUMPTION AND RUNNING COSTS

THE preceding Chapters have contained a very large number of figures relating to the power consumption and running costs of the various furnaces and processes described. It is the author's purpose in this, the final Chapter of the book, to reduce this mass of data to a form in which the results may be more easily compared. It is necessary to note, however, that when all the values of power, weight, and value have been reduced to one common form of expression, there will still remain the differences due, (1) to the greater or less impurity of the pig-iron and steel used for the refining process; and (2) to the extent to which the electric refining operation is varied in the production of a pure product; and (3) to the varying rates of wages and costs of materials in the different countries. For these reasons, comparative power and costs data require most careful investigation and study before they can be used as guides to the relative efficiency of competing electric steel-refining furnaces and processes. In those cases where no chemical analyses of the raw materials and finished steel are given, the data are, for comparative purposes, practically worthless. Even when full details of the chemical and physical tests have been presented, only a practical steel-maker and metallurgist can judge of the comparative efficiencies of the refining processes.

The author proposes, therefore, in this Chapter merely to present all the available data in the form in which it can be most easily made use of, in order to arrive at an independent and reliable judgment upon the various furnaces and processes of electric steel refining; and each steel-maker will be expected to decide for himself which of these furnaces and processes is the most suited to his own particular requirements.

The Heroult Furnace and Process.

The most reliable figures relating to the Heroult furnace and process are those given by Osborne (see Chapter IV., p. 55) for the working of the 15-ton furnace installed at the South Chicago Works of the U.S.A. Steel Corporation. These figures show that when using oxidised blown metal from the Bessemer converter of the following average composition :—

Carbon ·075 per cent. Phosphorus ·095 per cent.
Silicon ·010 per cent. Sulphur ·055 per cent.
Manganese ·075 per cent.

1,350 kw. applied for one and one-third hours, equal to 119 kw. hours per ton of 2,000 tons, could produce a deoxidised steel, low in sulphur and phosphorus, and within reasonable limits of practically any analysis required. The physical tests of these steels showed 35,000 to 47,000 lbs. for elastic limit, 60,000 to 70,000 lbs. for tensile strength, and 25 per cent. to 30 per cent. elongation.

Independent data from *Metall. and Chem. Engineering*, quoted in the course of the same Chapter, showed a lower consumption of 103·8 kw. hours per ton of 2,204 lbs., for this same South Chicago furnace, with an average composition for eight successive heats of carbon ·40 per cent., sulphur ·029 per cent., phosphorus ·030 per cent.

As regards *Costs*, the consumption of electrodes at South Chicago is stated to amount to 6 lbs. carbon per ton of finished steel, and the cost of roof and hearth repairs is placed at the low limit of 6 cents per ton.

Figures given by Eichoff, for the operation of a 3-ton Heroult furnace at the works of Richard Lindenberg et Cie at Remscheid, show a power consumption of 200 kw. hours per metric ton, when using highly oxidised steel charged hot from a Wellman open-hearth furnace. The raw material in this case contained on the

average ·01 per cent. phosphorus ; this was reduced by the electric refining process to an average of ·004 per cent., while the sulphur in the finished steel fluctuated between ·007 per cent. and ·012 per cent. The above figures indicate that when molten metal from the Bessemer converter or Wellman open-hearth furnace is employed as raw material, the melt requires between 100 and 200 kw. hours to complete the refining process, the power consumption being lowest in the larger furnace.

As regards the average power consumption of furnaces working *with cold scrap*, the melting and refining process being carried out with two slags, the following figures were given in Chapter IV. for the output of a 2½-ton Heroult furnace at La Praz, France, during the week ending December 24th, 1911.

Total metal refined, 62 tons 14 cwts. in 26 heats, equal to 126 hours. Average power consumption for week, 528 kw. hours per metric ton. Lowest power consumption for week, 459 kw. hours per metric ton.

Taking the cost of power at South Chicago at ½ cent. per kw. hour, we find that the energy required to carry out the electric refining process at this place represents only an addition of between $0·50 and $1·00 per ton to the cost of the finished steel, while the costs for electrodes and repairs would not add more than 10 cents per ton to the above figures.

At Sheffield, where the cost of electric power (as generated from coal by the Corporation Electricity Works) is ·48 penny per kw. hour, the cost of refining molten metal will probably run between 4*s.* 6*d.* and 8*s.* 6*d.* per ton, and when cold scrap is used as raw material for the electric furnaces, the costs will rise to between 19*s.* and 21*s.* 6*d.* per ton.

The Girod Furnace and Process.

The figures for the power consumption and working costs of the Girod furnace and process given in Chapter V. were supplied by the owners of the patents, and are based upon the work at Ugine. They are doubtless not so convincing as independent test results, but may be regarded as trustworthy. It must be pointed out that the more reliable estimates are based on the use of cold scrap as raw material of the refining operation, Girod believing that the quality of the steel produced is superior when starting with cold metal. The power consumption was recorded at the terminals of the furnace, and included smelting, refining and finishing a charge of cold scrap. It amounted to 850 kw. hours for a 3-ton furnace, and to 750 kw. hours for a 10-ton furnace. The figures, of course, varied with the composition of the charge, and according to the quality of the steel produced.

The consumption of electrodes per ton of steel made was about 8 to 9 kgs. for the 3-ton furnace, and 8 to 10 kgs. for the 10-ton furnace.

The following estimates of costs are based on the Ugine results, and upon the prices of raw materials, rates of pay, etc., obtaining in the south-east district of France.

TABLE XXXVII.

COLD CHARGES.

—	3-ton furnace.		10-ton furnace.	
Raw Materials.				
Scrap—1,100 kgs. at 75 frs. per 1,000 kgs.	82·50		82·50	
Slags	2·30		2·30	
Deoxidising additions and recarburisation	3·50		3·50	
		88·30		88·30
Producing Costs.				
Electric power—850 and 750 kw. hours at 2 cents per kw. hour	17·0		15·00	
Electrodes, at 320 frs. per 1,000 kgs.	3·0		3·50	
Wages	3·0		1·50	
Maintenance and repairs per 1,000 kgs.	12·0		8·00	
		35·00		28·00
Total cost, in frs. per 1,000 kgs. .		123·30		116·30

TABLE XXXVIII.

MOLTEN CHARGES.

—	3-ton furnace.		10-ton furnace.	
Raw Materials.				
Liquid steel (4 per cent. loss in heating) 1,040 kgs. at 80 frs. per ton . .	83·20		83·20	
Slags	2·00		2·00	
Deoxidising additions	3·50		3·50	
		88·70		88·70
Cost of Production.				
Electric power—275 and 200 kw. hours at 2 cents per kw. hour	5·50		4·00	
Electrodes, 3 to 4 kgs., at 320 francs .	1·25		1·25	
Wages, 8 heats in 24 hours	1·00		1·00	
Maintenance and repairs of the furnace	4·00		2·50	
		11·75		8·75
Total cost, in frs. per 1,000 kgs. of steel		100·45		97·45

These estimates do not include the expenses for ingot moulds, superintendence and laboratory charges, depreciation and general charges, which vary too considerably to allow a good average to be established.

As regards the chemical composition of the raw materials and finished steel, the following are the average tests of the scrap material used and refined metal produced, at the Ugine Electric Steel Works:—

TABLE XXXIX.

Scrap Material.	Per cent.	Finished Steel.	Per cent.
Carbon	·35	Carbon	·04 to 1·50
Silicon	·20	Silicon	·20
Manganese . . .	·70	Manganese . . .	·30
Sulphur	·095	Sulphur	·015
Phosphorus . . .	·095	Phosphorus . . .	·015

The physical tests of the steel produced at Ugine by the Girod furnace and process range from 39,000 lbs. up to 114,000 lbs.

for elastic limit; from 50,000 lbs. up to 142,000 lbs. for tensile strength; and from 33 per cent. down to 9 per cent. for elongation under stress.

The Stassano Furnace and Process.

The following figures are given in Chapter VI. for the power consumption and working costs of the Stassano furnace and process as worked at Turin; in each case cold scrap being used for charging the furnaces:—

TABLE XL.

200 h.p. Furnace.	Power Consumption.	Output.
Steel for Projectiles . .	1,250 kw. hours per metric ton .	653 kgs.
Mild Steel for Castings .	1,260 kw. hours „ „ .	730 kgs.
1000 *h.p. Furnace.*		
Steel Ingots for Projectiles	958 kw. hours per metric ton .	3,900 kgs.
	918 kw. hours „ „ .	3,900 kgs.

As regards the consumption of electrodes and costs for refractory materials for linings, etc., the trials at Turin gave the following figures per ton of steel produced:—

Electrodes . . .	10 kgs.	2*s.* 6*d.*
Refractory materials . . .		8*s.* 0½*d.* to 12*s.* 1*d.*

A complete estimate of costs based on the trials at Bonn in Germany gave the following figures:—

TABLE XLI.

	Per metric ton of cast steel. £	*s.*	*d.*
(1) Raw materials; including additions of chromium to finished steel	3	9	5
(2) Electric power (1,000 kw. hours at ·536 penny per kw. hour)	2	4	8
(3) Refractory materials for linings	0	11	10
(4) Labour	0	9	11
(5) Interest and depreciation	0	4	11
(6) Electrodes	0	2	6
(7) Water for cooling purposes	0	0	6
	£7	3	9

As regards the chemical and physical tests of the steel produced in the Stassano furnace, the following figures were given by Catani in the paper read before the Iron and Steel Institute in London in October, 1911:—

TABLE XLII.

CHEMICAL TESTS.

Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
·235	·195	·047	·031	·546
·207	·236	·043	·027	·421
·360	·140	·052	·036	·486

PHYSICAL TESTS OF THE SAME STEELS.

No.	Tensile strength in lbs. per sq. in.	Elongation, per cent.
1	(Average) 61,726	18·2
2	(Average) 58,462	19·0
3	(Maximum) 63,855	19·4

The following are the average test results of steel made in the 1,000 h.p. furnace and intended for projectiles:—

TABLE XLIII.

CHEMICAL TESTS.

No.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	·310	·242	·037	·023	·877
2	·450	·061	·039	·029	1·211

PHYSICAL TESTS.

No.	Tensile strength in lbs. per sq. in.	Elongation, per cent.
1	82,302	21·4
2	99,330	17·1

The Kjellin and Röchling-Rodenhauser Furnace and Process.

The figures given in Chapter VII. show that, under the most favourable conditions, steel can be "melted" in the *Kjellin* furnace with an expenditure of 590 kw. hours per metric ton, but that the maintenance of the heat during the "killing" or degasifying period, adds from 60 to 200 kw. hours to this total.

Tests made with a 125-kw. furnace of the original Kjellin type have shown that 1 metric ton of ordinary tool steel can be made with an expenditure of 650 kw. hours, while the highest grade steel requires from 750 to 800 kw. hours.

As regards the power consumption and costs of operating the "combined" or *Röchling-Rodenhauser* type of induction furnace very full estimates and costs figures are available. According to Härden, when molten metal from the Bessemer converter is charged into the furnace, only from 125 to 150 kw. hours are required per ton of finished steel, and 130 kw. hours may be taken as a good average.

Vom Baur, in a letter published in the issue of the journal named below,[1] gives 200 to 250 kw. hours per metric ton for the work of a 10-ton furnace refining basic Bessemer steel, which contained before treatment in the electric furnace ·08 per cent. phosphorus and ·09 per cent. sulphur and only one-tenth of these amounts after the refining operation. According to the same authority, the R.R. type of induction furnace will *melt* cold scrap with an expenditure of 580 kw. hours per ton, and the following estimates of the conversion costs of a 2-ton furnace operated at Volklingen were given by him in a paper read in 1911 before the American Foundrymen's Association.

Table XLIV.

		Per long ton.
700 kw. hours for melting at ·6 per cent. per kw. hour.	$4·20	
200 kw. hours for refining at ·6 per cent. per kw. hour	1·20	
	——	$5·40

[1] *Metallurgical and Chemical Engineering*, January, 1912.

Table XLIV.—*continued.*

	Per long ton.
Fluxes, etc., roll scale 22 lbs., lime 77 lbs., fluorspar 11 lbs., sand 20 lbs., ferro-manganese 8·8 lbs.	·44
Loss of fluxes owing to quarter of all metal remaining in the hearth	·16
Labour (at American rates of pay), 2 to 3 men .	1·50
Tools, repairs and lining	·67
Depreciation 10 per cent., interest 5 per cent. on $11,000 for 300 days, 6 tons per day of 12 hours. $1695 ÷ 1800 = . . .	·94
Auxiliary apparatus (cooling air for transformer)	·04
Total	$9·15
Adding this, we get:—	
Raw materials	12·60
Conversion costs	9·15
Cost of one ton electric steel ready to pour . .	$21·75

To this cost must be added a slight licence fee per ton, depending on the output. Time of heat, about four to four and a quarter hours.

Working with hot metal (drawn from the blast furnace, mixer, cupola, or other type of furnace), the consumption of power is, of course, considerably reduced, and the following figures are given by Vom Baur in the paper referred to above.

Table XLV.

Cost of refining hot metal taken from the Wellman Mixer at Dommeldingen allowing for American conditions, and for a 5-ton furnace:—

Raw materials	$12·00	
Oxidation loss 3 per cent.	·36	
	——	$12·36
Current — 280 kw. hours at ·6 cent per kw. hour		1·68
Fluxes, etc.		·60
Labour		·50
Tools, repairs and lining		·64

TABLE XLV.—*continued.*

Depreciation 10 per cent., interest 5 per cent. on $17,000 for 300 days at 40 tons per day of 24 hours, $2,550 ÷ 12,000 tons =	·22
Auxiliary apparatus	·06
Total	$16·06
Cost of preliminary refining, about . .	3·00
Total cost of 1 ton of electric steel ready to pour	$19·06

Time of each heat about 2½ hours.

The estimated cost of refining hot metal, melted in the cupola, and consisting mainly of steel scrap, having about 2 per cent. carbon in the resultant mixture, is as follows:—

TABLE XLVI.

Raw materials	$14·00	
Total oxidation loss, 8 per cent.	1·12	
		$15·12
Conversion cost similar to the above . .		4·90
Cost of preliminary melt in the cupola, about		3·00
Cost of 1 ton of electric steel ready to pour .		$23·02

Time of each heat about 3½ hours.

A more detailed estimate of cost for English conditions of work was given by Kjellin in a paper contributed to the Niagara Falls Meeting of the American Electro-chemical Society, held in May, 1909. The production cost of steel for rails in a 7-ton three-phase Röchling-Rodenhauser furnace was given in this paper as 74*s*. 8*d*. per ton, and for soft boiler-plate as 79*s*. 3*d*. per ton.

As a final estimate of power consumption and costs, that given by Thieme in an article contributed to the journal named below[1] may be quoted. The estimate is for steel produced in a

[1] *Electrotechnische Zeitschrift*, September 8, 1910.

three-phase R.R. furnace, of 5-ton capacity, using fully-blown molten raw material containing 0·8 per cent. phosphorus; 0·8 per cent. sulphur and ·12 per cent. carbon, and with power costing 4·5 pfg. per kw. hour. It is assumed that this furnace can produce annually 10,000 tons of finished steel, in 250 working days of 8 heats per day.

TABLE XLVII.

	Marks per Ton of Finished Steel.
Depreciation on 10,000 marks	1·00
Power consumption, 280 kw. hours . . .	12·60
Materials for slags, etc.	2·25
Linings and repairs	2·50
Wages	·75
Air-blast for cooling transformer coils . .	·21
	19·31 marks

This total, equivalent to 19*s*., is one for running costs only, no estimates for the cost of raw materials, or for the interest and royalty charges having been included in it.

As regards the degree of purification effected by the Röchling-Rodenhauser type of furnace, the average of the three tests of rail-steel given by Härden shows ·035 per cent. S.; ·048 per cent. P., and a tensile strength of 52·5 tons per square inch. The average of the tests given by Vom Baur for various steel products shows ·008 per cent. S.; ·0095 per cent. P., and an average tensile strength of 89,600 lbs. per square inch.

The corresponding chemical tests, for the raw materials used in making these steels, are not given.

The Keller Furnace and Process.

The only figures for the power consumption and running costs of the Keller electric refining furnaces are those emanating from the patentee, and published in Chapter VIII., p. 131. They relate to the work done with the 8-ton furnaces of the earlier type at Unieux in 1908, and are based on the use (as raw material) of molten metal from a Martin open-hearth furnace. The following are the figures as given by Keller in one of his numerous papers:—

TABLE XLVIII.

Molten metal charged, 7,500 kgs.
Composition of ditto; carbon, ·15 per cent.; sulphur, ·06 per cent.; phosphorus, ·007 per cent.
Mean power consumption, 750 kw.
Carbon contents desired, ·45 to ·50 per cent.
Time of refining operation, 2 hours 45 minutes.
Composition of finished steel. Carbon, ·443 per cent.; sulphur, ·009 per cent.; phosphorus, ·008 per cent.
Power consumed per metric ton, 275 kw. hours.
Electrode consumption, 10 kgs., costing, at 40 frs. per 100 kgs., 4 frs. per ton.

No figures showing the power consumption or running costs of the later type of Keller furnaces have been published.

The Frick Furnace and Process.

The power consumption of the Frick electric induction furnace, according to Lyman (see Chapter IX., p. 139), is 600 kw. hours per ton for melting the cold scrap, and 180 to 200 kw. hours per ton for refining, a total of 780 to 800 kw. hours per ton of finished steel.

The Hiorth Furnace and Process.

According to the figures given by Richards (see Chapter IX., p. 145), 530 to 550 kw. hours are required to melt one ton of pig-iron and Walloon bar-iron in the Hiorth induction furnace,—and under regular conditions of work, 150 kw. to 170 kw. hours are required to complete the refining operation. This equals a total of 680 to 720 kw. hours used per ton of cold metal charged. In the melt of which full details are given however, the power consumption was 790 kw. hours per ton of metal.

The Colby Furnace and Process.

The trials of the small experimental furnace at Tacoma, U.S.A., showed a power consumption of between 605 and

825 kw. hours per metric ton of metal poured (see Chapter X., p. 157).

. . . .

In order to enable the more important figures given in the course of this Chapter to be compared, they have been reduced to a common basis, and are presented in Tables XLIX and L.

Table XLIX., showing the *Power Consumption* of the various furnaces is most instructive and will repay careful study.

Table L., giving the figures for the *Chemical and Physical Tests* of the raw material used and finished steel, must be studied in the light of the footnote attached to the Table.

The Running Costs cannot be compared satisfactorily by any method of tabular statement, since the costs of raw materials and other data upon which the estimates for the different furnaces and processes are based, vary so greatly. It may be stated, however, that other charges being equal, the furnace and process that has the smallest power consumption will prove the cheapest to work, for the cost of power in every case is one of the main items in the total operating costs. The cost of linings and repairs is another important item, which varies greatly with the different types of furnace. It is perhaps necessary to emphasise the fact that this has a considerable influence upon the total running costs of the installation. Frequent repairs mean that frequent stoppages of the furnace are necessary in order that these repairs may be carried out, and these stoppages not only cause loss of heat, but also diminish the output of the furnace, and consequently increase the interest and depreciation charges per ton of finished steel.

This is one feature of the repairs question that is sometimes overlooked by patentees and electro-metallurgists without practical works experience, who have failed to realise that a large and steady output is an essential condition of success in all furnace operations when carried on upon an industrial scale.

Table XLIX.

Power Consumption in kw. hours per Metric Ton (2,204 lbs.) of Steel Produced.

Type of Furnace.	Cold charges composed of: Scrap.	Pig-iron and Walloon iron.	Average.	Molten charges from: Bessemer.	Wellman open hearth.	Martin open hearth.	Cupola.	Average for molten charges.
Heroult	459	—	—	104	—	—	—	—
	528	—	493	133	200	—	—	146
Girod	750	—	—	—	200	—	—	—
	850	—	800	—	275	—	—	237
Stassano	918	—	—	—	—	—	—	—
	958	—	—	—	—	—	—	—
	1,000	—	—	—	—	—	—	—
	1,250	—	—	—	—	—	—	—
	1,260	—	1071	—	—	—	—	—
Kjellin	650	—	—	—	—	—	—	—
	790	—	—	—	—	—	—	—
	800	—	747	—	—	—	—	—
Röchling-Rodenhauser	640	—	—	125	—	—	—	—
	—	—	—	150	280	—	280	—
	780	—	—	200	—	—	—	—
	900	—	773	250	—	—	—	214
Frick	780	—	—	—	—	—	—	—
	800	—	790	—	—	—	—	—
Keller	—	—	—	—	—	275	—	275
Hiorth	—	680	—	—	—	—	—	—
	—	720	—	—	—	—	—	—
	—	790	730	—	—	—	—	—
Colby	605	—	—	—	—	—	—	—
	825	—	715	—	—	—	—	—

Table L.

Chemical and Physical Tests of Steel Produced.

Type of Furnace.	Chemical Tests: Per cent. Carbon.	Per cent. Sulphur.	Per cent. Phosphorus.	Physical Tests in lbs. per sq. in.: Elastic Limit.	Tensile Strength.	Elongation Per cent.
Heroult	—	*·055*	*·095*	35,000	60,000	25
	·40	·029	·030	↓	↓	↓
	—	·009	·004			
	—	·012	—	47,000	70,000	30
Girod	·350	*·095*	*·095*	39,000	50,000	9
	·040	·015	·015	↓	↓	↓
	1·500	—	—	114,000	137,000	33
Stassano	·267	·048	·031	—	61,300	18
				—	↓	↓
	·380	·038	·026	—	90,816	19
Röchling-Rodenhauser	—	*·090*	*·080*	—	89,600	—
	—	·009	·008	—	↓	—
	—	·035	·048	—		—
	—	·008	·0095	—	117,600	—
Keller	*·15*	*·060*	*·007*	—	—	—
	·44	·009	·008	—	—	—

Note.—The chemical tests in the above Table represent the *averages* for particular classes of steel. The tests in italics show the average composition of the raw materials used. The tests immediately below these represent the tests of the steel produced from these same raw materials.

The physical tests are the highest and lowest figures for the steels produced by each type of furnace; some of these being special alloy steels.