Center for Air Environment Studies
The Pennsylvania State University

CUPOLAS MINIMIZE THE ENERGY REQUIRED TO MELT FERROUS ALLOYS

by

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MASTER

May 1979

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Center for Air Environment Studies
The Pennsylvania State University
University Park, Pennsylvania 16802

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ABSTRACT

Historically the cupola has been the most effective furnace for melting cast irons. Although its supremacy was challenged by electric melting furnaces in the 1960's, persisting energy scarcity and high cost have encouraged a resurgence of interest in cupola technology. Using the optimum design features of modern cupolas and the best melting practices, they can achieve melting efficiencies of 45% or more based on the energy value of the original coal. In contrast, electric melting only uses 21% of the energy in coal. Despite these facts, many foundrymen fear that there will be problems because of poor metallurgical control if they use cupolas. Yet experience has proven otherwise. In terms of energy conservation and economy it is better to use large cupolas as scrap melters in the steel industry. Yet there is still a deep rooted prejudice against the cupola plus basic oxygen furnace route to steel making.

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The cupola may be defined as a vertical shaft melting furnace which uses coke as its fuel (1*). Air is introduced near the bottom through tuyeres (Fig. 1). The fuel, flux and metal charge materials are introduced in discrete batches through a charging door located 5 to 10 cupola diameters above the bottom doors. Molten metal and slag are continually tapped at the spout and hot gases are passed through a bag house prior to discharge to the atmosphere. The melting process may continue on a 20 hour per day basis for two or more weeks.

Cupola melting is inherently efficient because it is the only melting process which brings the fuel and the raw materials into intimate contact during operation. However, the most significant feature of cupola melting is the potential for achieving even greater efficiencies in the future.

Since the 1950's there has been a large number of advances in cupola technology. These can be summarized as improvements in cupola design, cupola operation, cupola controls and metallurgical control.

1. Cupola Design
   a. Water wall
   b. Hot blast
   c. Divided blast
   d. Recuperative hot blast

2. Cupola Operation
   a. Oxygen injection
   b. Coke breeze injection
   c. Least cost charge calculations
   d. Induction heated forehearth
   e. Vibratory feeding of charges

3. Cupola Controls
   a. Blast temperature control
   b. Blast humidity control
   c. Air weight control
   d. On line computer control

4. Metallurgical Controls
   a. Continuous external desulfurization
   b. Wire feed inoculation
   c. Continuous addition of SiC at spout
   d. Reading of C, Si and carbon equivalent at spout
   e. Improved metal treatment

* Numbers in parentheses designate References at end of paper

With these improvements in cupola technology and operating practices come a growing need for technically competent personnel. Without a properly educated individual who feels pride in making the melting operation a metallurgical and economic success, the chances of achieving optimum are reduced. Finding and developing suitable personnel is crucial. In this respect the Foundry Educational Foundation of Cleveland, Ohio is succeeding in stimulating the interest of many technically oriented young people.

ENERGY CONSUMPTION IN CUPOLA MELTING

There are several ways to estimate the energy required for melting iron and steel in a cupola. The mass balance approach is undoubtedly the most effective. Two analyses have been published based on this method. The results of several analyses of the energy required in cupola melting are shown in Table 1 and Table 2.

Table 1. Energy Required in Cupola Melting

Cupola Size (I.D.) (in.)	Blast Type	Melting Rate (t/hr)	Energy Used (Btu/ton)	Reference Source
66	Warm	21.9	2.6×10^6	2
72	Cold	24.1	3.7×10^6	3
150	Hot	∿100	8.6×10^6	4*
150	Hot	∿100	9.4×10^6	5*

* Includes the energy for the BOF production of steel.

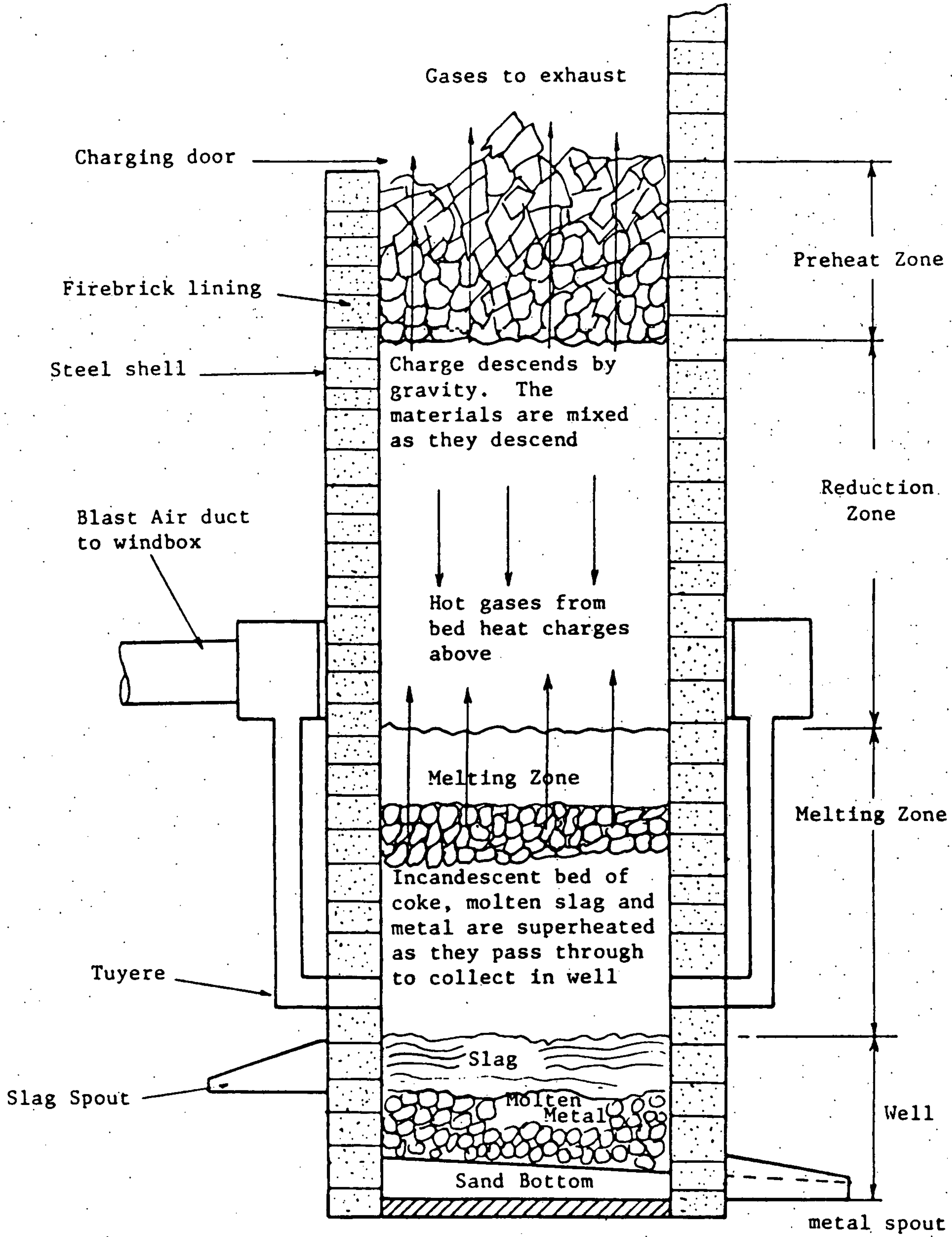

Figure 1. Schematic Diagram of a Conventional Cupola

Table 2. Effect of Operating Strategies on Energy Required in Steelmaking (4)

Operating Strategy	Scrap (%)	Energy Req'd** (10^6 Btu/t)
BF + BOF with ore trim**	0	27.5
EAF + 100% dir. red. ore	0	26.7
BF + BOF with scrap + ore trim	25	22.6
BF + BOF with scrap trim	30	21.7
EAF + 50% dir. red. ore	50	16.9
BF + open hearth with O_2	50	15.8
BF + open hearth with O_2	70	12.5
HBC + BOF with scrap trim*	100	8.6
EAF	100	7.0
Open hearth with O_2	100	6.7

BF = blast furnace
EAF = electric arc furnace
HBC = hot blast cupola*
**Scrap energy value = 0

It should be noted that there is a wide divergence in the results reported in Table 1. This occurs primarily because the mass balance calculations are based only on the melting energy required within the cupola. They do not include energy needed for heating the forehearth, operating the environmental control equipment or for external desulfurization. The calculations of the energy usage in the large cupolas involved in steel production include the energy required to produce the oxygen used in the BOP vessel. The carbon boil reaction is exothermic and is fueled by the carbon picked up by the hot metal during the melting operation. It appears that the energy required to produce steel using large cupolas is overstated by some 10 or more percent. A much more detailed energy analysis would be required to determine the source of this discrepancy.

RECYCLING FERROUS SCRAP

Not only has the large cupola become economically attractive as a scrap melter, but it makes available a technology which has been largely ignored in the United States up to the present time. In times of national energy shortages it is even more vital to seek ways to reduce energy consumption to a minimum. It is important to realize that with every ton of scrap metal exported from the United States, the equivalent of 24×10^6 Btu of energy is exported also. That is a net energy loss of 36×10^{13} Btu annually which must be replaced by mining, beneficiation and reduction of ore at an expenditure of 40×10^{13} Btu.

If in fact domestic scrap can be turned to steel by the recuperative hot blast cupola and BOF route, a net energy use of 5.5 to 6.5×10^6 Btu per ton would seem to be a reasonable energy requirement. However, even if developed, the scrap melters would only produce some 20-30% of our annual steel output.

The coal energy required to produce 7.0×10^6 Btu/ton of electric energy would be equivalent to be about 33×10^6 Btu/ton whereas the total fossil fuel energy required for the cupola plus the BOF route would require about 15×10^6 Btu/net ton of equivalent coal energy.

At this level of potential energy savings it is obviously in the best interests of the steel industry and the American public to use this improved technology which is not only energy efficient but which is also economically viable.

FUTURE DEVELOPMENTS

Many prophets of doom are skeptical about the future of American coking coals. There are undoubtedly sufficient supplies for the near term, but what about long term developments? There is a good possibility of developing a suitable low reactivity form coke for cupola melting which would make the cupola melting process even more attractive from the economic viewpoint.

Today briquetted coke breeze and coke breeze injection into the combustion zone of a cupola are being used successfully to improve melting efficiency. If these innovations are developed to their full potential, cupola melting will become even more beneficial as an energy conserver.

In the foreseeable future a new type of form coke should emerge. It would have the low initial reactivity which is needed to make it suitable for passing through the preheat zone without combustion, but then it would develop the high reactivity needed for good melting in the combustion zone. In fact it may be possible to use a heat treating process to remove the iron pyrites from the coal before briquetting, thus making a low sulfur compact. This would add immeasurably to the value of that type of form coke as a cupola fuel.

SUMMARY AND CONCLUSIONS

It is evident that cupola melting is both economically and energetically feasible at the present time. New developments in coal technology may make cupolas the predominant melting furnace for gray iron and scrap steel production. The divided/hot blast cupola with coke breeze injection and thermal recuperation, can be up to 50 percent energy efficient. More important, large cupolas are potentially much more likely to have improved energy usage than electric arc furnaces for melting ferrous scrap for the steel industry. Their use could help the United States to reclaim and melt its 700×10^6 tons of ferrous scrap (6). Thus several conclusions can be reached:

(1) Cupola melting requires about 2.5×10^6 Btu/ton which is considerably less energy than any other melting process.

(2) Large cupolas for melting ferrous scrap are economically and technically feasible.

(3) The use of large cupolas will require the training of many new people in the modern technology required for their operation.

(4) The scrap dealers and the federal government should get together to formulate scrap export policy relative to domestic shipment rates to encourage the use of domestic scrap and its inherent energy in the U.S. metal market.

(5) The country should make a consistent effort to exploit its own ferrous scrap, rather than to make new steels from virgin materials.

ACKNOWLEDGEMENT

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A GUIDE TO AIR POLLUTION RESEARCH (PHS) Publ. No. 981) was prepared in 1969 by the Center for Air Environment Studies under contract to the National Air Pollution Control Administration of the United States Public Health Service. It is available from the Superintendent of Documents of the Government Printing Office, Washington, D. C. 20402. The 1972 edition of the Guide was prepared by the Center under contract to the Office of Air Programs of the Environmental Protection Agency and is also available from the Superintendent of Documents.

HANDBOOK OF EEFECTS ASSESSMENT: VEGETATION DAMAGE was published in 1969. It describes in detail the many various sources of pollution and the effect of these pollutants on vegetation. Included are color slides depicting the characteristic symptoms of plant damage. This publication is available through the Center for Air Environment Studies.

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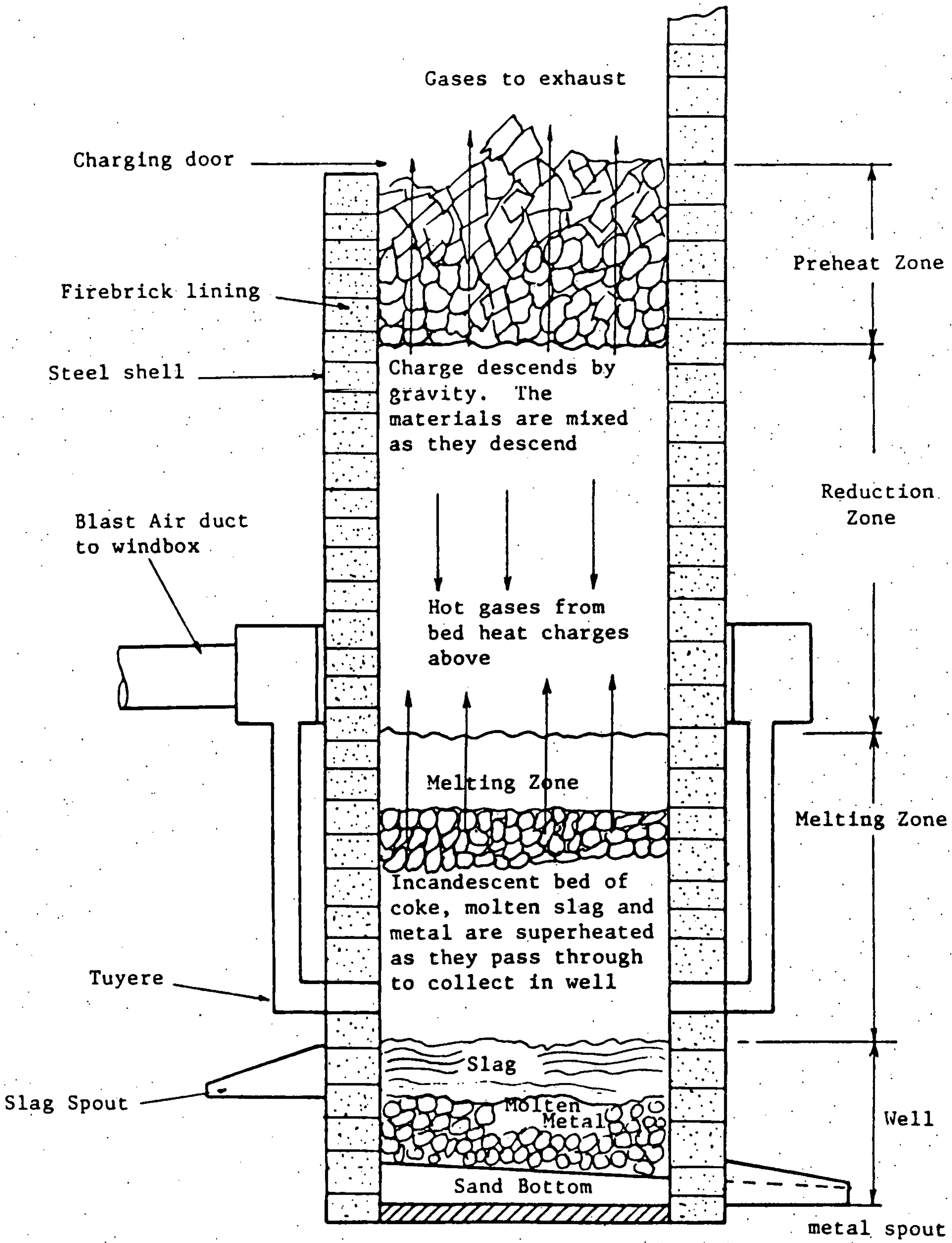

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