Some design and operational aspects of continuous weld mill furnace

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The paper deals with important aspects of design and operation of a furnace for continuous heating of skelp to make butt welded commercial steel tubes.

Details of furnace construction, combustion system, various ways of heat salvaging methods, refractory lining practice and methods of calculation of heat transfer, etc. have been described.

Some recommendations regarding further improvents in the areas of furnace efficiencies and maintenance practices have also been included.

Introduction

The steel tube industry in India had its begining only as recently as 1954. Today the lincensed capacity of steel tubes in the organized sectors of the country is approximately 2 million tonnes[1].

Continuous butt weld tube making process also known as the Fretz Moon Process is a well tried and dependable method that results in sound weld[2].

Indian Tube Co. Ltd. has two continuous weld mills (installed capacity, 1,75,000 tonnes per annum) in which steel tubes in the size range, 15 mm to 80 mm nominal bore are produced.

The furnace employed for continuous weld mill process constitutes the largest portion of the system and does not follow any conventional design or operational practice as applicable to most of the reheating furnaces. The present object, therefore, is to study various design features and operational practice of such an uncommon reheating furnace.

Since nature of construction and operation of both C. W. Mill furnaces in I. T. C. are of similar type, only No. I mill furnace has been considered in details.

Fretz moon process

A diagrammatic layout of C. W. tube plant No. I of I. T. C. is shown in Fig. I. The fretz moon process[2,3]

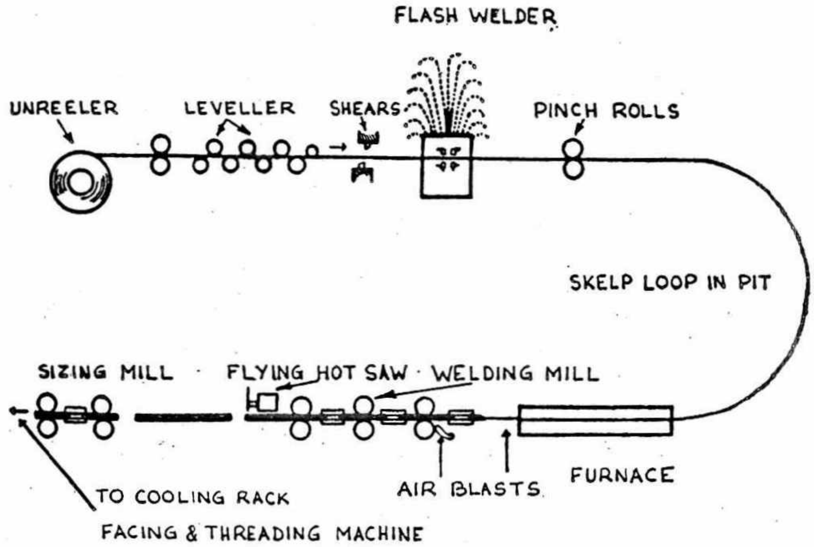

Fig. 1 Layout of No. 1 continuous weld tube plant of Indian Tube Co Ltd.

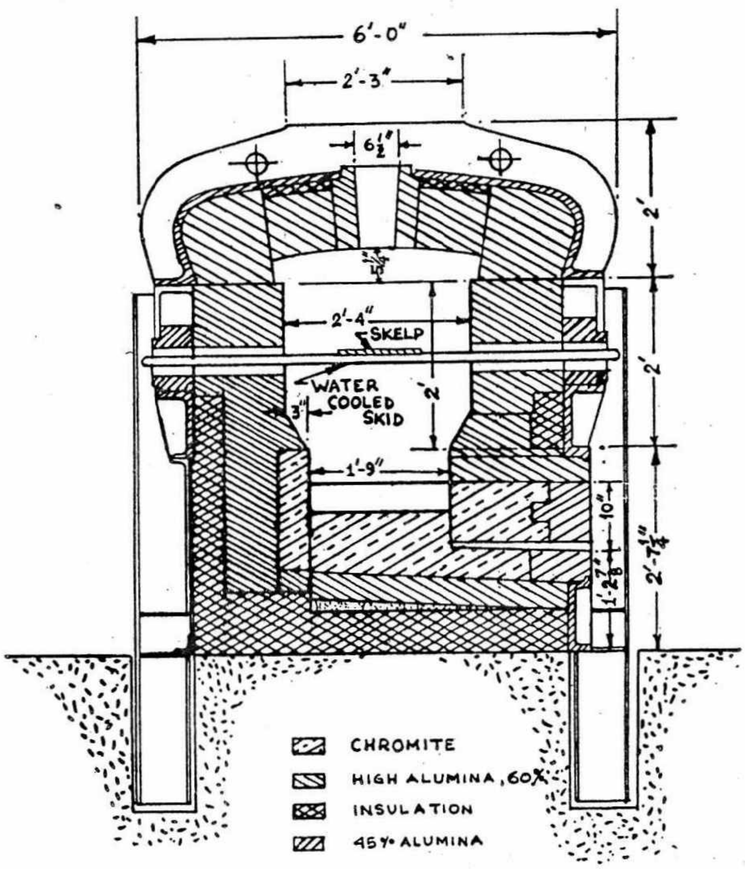

Fig. 2—Cross sectional view of continuous weld mill furnace at Indian Tube Co. Ltd.

TABLE—I

Basic design data of No. 1 continuous weld mill furnace at I. T. C.

Furnance capacity	...	24 M. Tons/hour
Length	..	130 ft. 5½ inches
Width	...	2 ft. 4 inches at Top and 1 ft. 9 inches at bottom
Height	...	3 ft. 1.7/8 inch
No. of zones	...	4
No. of water cooled skid pipe	...	13
Gas consumption	...	120×10^3 c. ft,/hour.
No. of burners	...	246
Capacity of burners	...	500 cft of coke oven gas/hr.
Fuel	...	Coke oven gas (450 Btu/cft., Av. calorific value)
No. of recuperator chambers	..	4
Top element temperature of recuperator	...	900 °C max.
Combustion air temperature	...	450—500 °C
Height of chimney	...	150 ft.
Mill speed, fpm	...	480—120

essentially consists of bending an endless skelp in hot condition to form a circular section and then welding the seam continuously. The skelp comes in the form of coil which are progressively unwound and welded by flash welding unit end to end to give a continuous ribbon of strip. It is then passed through the long tunnel type reheating furnace. As the skelp passes through the furnace, it is progressively heated from room temperature at the entry end to body temperature of about 1280 to 1320 °C with edges 40—80 °C higher. Immediately, after the skelp leaves the furnace, a blast of air (some times enriched with oxygen) at 26" wg is blown on both edges to remove all oxides and clean the edges, besides raising the edge temperature further. The hot skelp then passes through the welding mill rolls where the tube is formed and welded. The welded tube is then reduced to size in successive passes and cut to lengths.

Furnace

The furnace in the above process plays an important role and differ from any conventional reheating furnace design and operational practice. Cross sectional view of the furnace is shown in Fig. 2 and its basic design data is given in Table I. In this type of furnace the stock (skelp) does not rest on hearth and it moves axially over water cooled skids. For this process of heating, temperature uniformity in the skelp is not the object, the purpose is to heat the edges of strip to white hot (dripping) temperature which is higher than the body of skelp. This enables a much higher pressure to be applied in the welding pass and there by to obtain a weld of higher quality. The skelp must be heated in short interval of time 16.3 to 65 seconds to maintain high output of mill. This requires higher temperature of furnace gases which may be as high as 1650 °C.[4]

The furnace is of tunnel like construction, 130 ft. 5.5 in long with width of 21 in. at the bottom inside and 28 in. at the top and an average height of 3 ft. 1.7/8". The whole length of the furnace is divided in 4 sections, each having its own fuel distribution, combustion and offtake for its system. The furnace thus in effect can be conceived as if consisting of four independent furnaces joined end to end. 246 small burners each with maximum heating capacity of 500 cft. of coke oven gas per hour are fitted along both side walls. Arrangements are also provided for oil firing in Sections 1 and 2 as an alternative method when sufficient coke oven gas is not available.

The products of combustion rise out of the furnace chamber into vertical off-takes, then pass through horizontal cross-overs and are pulled down into the recuperators. The recuperators, along with their frame work rest on floor and extend upto the horizontal cross-overs. After, passing through the recuperators, the gases go down into a longitudinal flue running parallel to the furnace and finally to the stack.

There are several design features in the furnace. As the process is continuous, the operation can not be stopped for minor emergencies in the mill. Means are therefore, provided for instantaneous shutting off the fuel supply during such emergencies to enable the mill to run at a slow speed without burning of the skelp. Thus furnace is subjected to wide fluctuations of temperature which cause high thermal stresses in the refractory lining and necessitates frequent repairs. To enable such maintenance during down time, 22 numbers of removable covers are provided for the entire length of the furnace. The furnace cover having cast iron frame in the form of bung arch and ribs are provided not only to strengthen the frame but also for quick radiation of the outside surface[3] and this in turn increase refractory life.

The furnace temperature at the charging end is maintained at 1100 to 1250 °C. and in the discharging section from 1450—1500 °C.

For providing top, bottom and side firing (so called tripple firing) the skelp passes through the furnace on water-cooled skid pipes (13 numbers) and these prevent the steel from touching the furnace bottom, where it might pick up slag or scale at high temperature.

Combustion system

The combustion system of continuous weld mill furnace consists of fuel train, burners, combustion air blower, flue gas off-takes and control system

The fuel-train is of conventional design. From a 12 in. dia. gas main 4 parallel branch lines were drawn. In these are fitted the "quick shut off" device. These branches feed gas to individual furnace sections, each of which is provided with two Nos. 4 in. dia. manifold running on either side. Total 30 numbers of burners are connected to each manifold.

The design of burners merit special mention. Since the width of combustion chamber is small, to avoid flame impingment on refractory wall, flame length should be short and sharp. Keeping in view the above requirements, attention must be given to ensure following :

i) Proper mixing of fuel and air

ii) Attainment of correct flame condition and allow maximum heat transfer to skelp.

iii) Control of hot gases to cause minimum damage to refractories.

Flame length is controlled by maintaining nozzle diameter of the burner small. Sharpness of the flame is outcome of rapid combustion which is

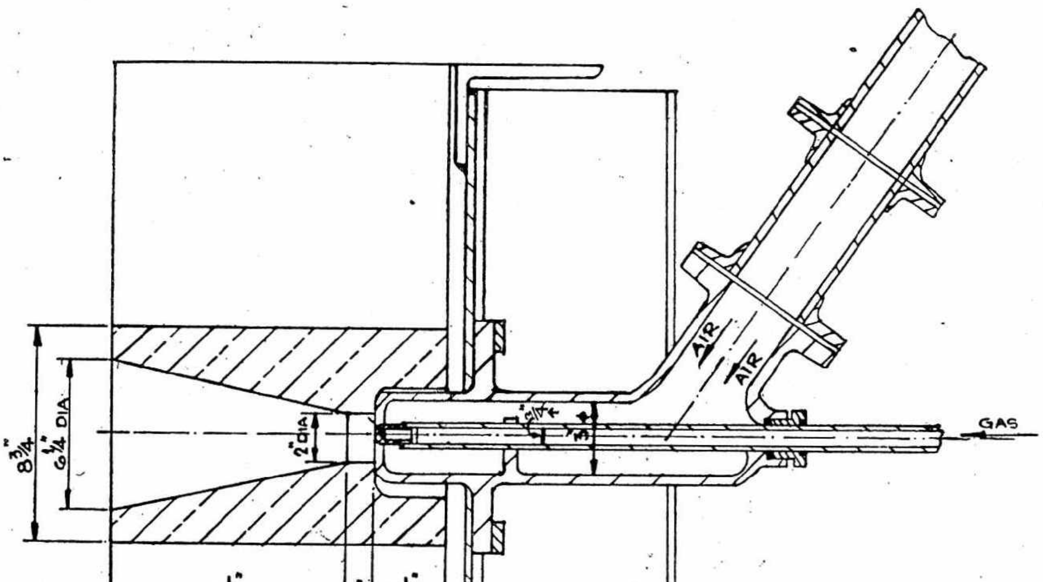

Fig. 3 Assembly of burner block

attained by maintaining relative velocity of efflux of gas and air high, angle of impingement wide and distributing the fluid (gas) into number of small jets. In Fig. 3 assembly of burner block with pipe, etc. is shown. The burner is a bloom type burner having 5 equally spaced small holes near the nozzle end. Replacing this type of burner with high velocity type has also been proved successful elsewhere. Experiments were also carried out in I. T. C. to use single hole (dia. 1/4") nozzle for burner with a view to avoid choking due to sediments in coke oven gas. However with such nozzle, desired shape of flame could not be controlled.

Combustion air is provided independently for each section by 37.5 h. p. tubro blower with maximum air flow, 2,20,000 cft/hr recuperator.

Position of vertical off-take over the roof is shown in Fig. 4. It is believed that if the number of off-takes were increased, a more rapid transfer of

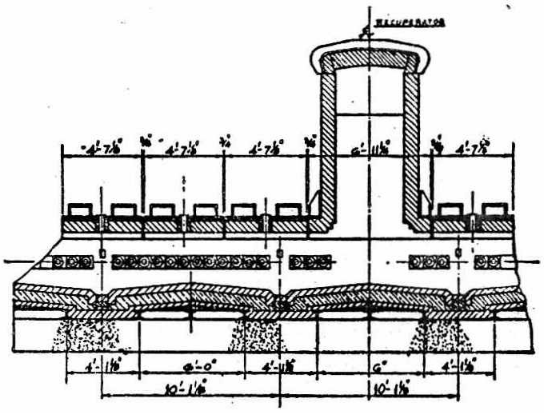

Fig. 4 A longitudinal section through the furnace showing position of uptake box.

heat could be obtained from the burners to the skelp.

For oil firing, L. D. oil is used and it is fed at 20 psi while the compressed air for atomization is kept at 22 psi. Depending on the requirement necessary numbers of oil burners are lighted up.

The furnace is equipped with automatic combustion control. The purpose of this control is to maintain a constant and uniform atmosphere within the furnace chamber. A slight oxidizing atmosphere is most suitable for this type of furnace as this ensures complete combustion of coke oven gas in the furnace. Further if unburned gases are left, they will burn near the recuperator which in turn can get damaged.

Heat salvage

The average operating temperature of the furnace being very high, the flue gases released from the furnace are at high temperature (1100 – 1400 °C) and these gases still contain good amount of heat. This heat amounts to about 60% of the potential heat of fuel gases. If this is allowed to leave unsalvaged, there will be substantial loss of valuable energy. It is with this object that 4 numbers metallic recuperator chambers are installed in this furnace. In addition, these assist as well, in providing necessary high flame temperature and rapid combustion required with this type of heating.

The recuperators at I. T. C. furnace No. 1 are composed of 90 numbers of needle shape elements arranged in 3 banks of 27, 27 and 36 elements. Top elements are made of 30—35% chrome alloy steel while the bottom two banks are of 2% chrome cast iron. Combustion air is forced through elements and preheated to a temperature of 450 to 500 °C, the elements being heated by waste products of combustion.

Automatic temperature control is provided for each recuperator to govern preheat temperature and to guard against excessive temperature, which might endanger metallic elements. Temperature within the recuperator is maintained around 900 °C by diluting the products of combustion entering the recuperators with free cold air. This air being controlled by motor operated valve actuated from control pyrometer.

To extract further heat from waste gases, the furnace is equipped with a waste-heat boiler having capacity of 5,000 lb of dry saturated steam per hour. Flue gas leaving waste heat boiler go to the chimney. Provision is also kept to pass the flue gases directly to the chimney.

Trinks et al[5a] have reported that heat consumption for a typical axial type continuous weld mill furnace can be of 4.5 x 10^6 Btu per metric ton, while minimum may be of the order of 2.8 x 10^6 Btu per m. t. Fuel consumptions for similar C. W. mill furnaces at Corby plant in U. K.[6] range from 4 to 6 x 10^6 Btu/Ton. Of course this depends on many factors such as type of burner, preheating temperature of skelp, fuel used and size of tube rolled etc. It may be noted that at I. T. C. between 1977-78 the average heat consumption for the C. W. mill furnace was 3.8 x 10^6 Btu per metric ton. The minimum recorded value in the corresponding period was 2.64 x 10^6 Btu. per metric ton of tube produced.

Refractories

In general refractories for Continuous Weld mill furnace have to withstand following service conditions :

i) High temperature

ii) Localised overheating due to flame misalignment or radiation from flame

iii) Temperature fluctuation and cycling

iv) Stresses and strain due to temperature gradient in the structure

v) Reaction due to scales, slag, etc.

The refractory construction in the furnace is as follows :

Sidewall

These are 13½" thick, comprising of 9" of 60% high alumina brick in the hot face which is backed up by 1½" insulation brick. However, lower part of the sidewall is laid with chrome brick in the hot face for superior resistance to iron oxide rich slag

Hearth

About 16½" thick with top layer 4½" chrome brick, which is followed

TABLE—II Specification of refractories used in continuous weld mill furnace

Type of refractories	P. C. E. (O.C.)	App. Porosity (Vol %)	C. C. S. Kg/Cm^2 (min)	R. U. L. ta, °C	PLC %	Spalling	Al_2O_3 %	Fe_2O_3 Max	Cr_2O_3 min	MgO min
Insulation brick	27	65 min	20	—	1.5 (1250°C 24 hrs)	—	35	1.5	—	—
45% alumina brick	33	24 Max	300	1500	±0.50 (1400°C 2 hrs)	good	45	1.8	—	—
High alumina brick	36	24 Max	350	1500	± 0.5 (1500°C 2 hrs.)	+ 30 Cycles	58—60	1.0	—	—
Chrome brick	38	25 Max	350	1450	—	—	—	—	40	20

by 7½" 60% H. A. brick and 4½" insulation brick. For easy flow of molten slag, hearth is shaped like a trough (see Fig. 4)

Roof

The construction is in the form of arch with 9" 60% H. A. brick backed by 1½" insulation brick

Uptake boxes, cross flues and recuperator chambers

In these areas 60% and 45% H. A. bricks are used depending on service conditions.

Details of specification of refractories used in I.T.C. are given in Table II. High temperature encountered in the furnace necessitates high grade refractories. Moreover refractories are subjected to severe stresses during rapid heating and cooling. Other than week ends, during operation periods also for some major or minor process emergencies in the mill, furnace is required to cool from 1500/1450 °C to 800/900 °C in very short interval and subsequently heated up again to maximum operation temperature.

Scale loss[6] in C. W. mill furnace is 3—4%. Therefore presence of iron oxide fumes and scales in various states of oxidation are very common in this type of furnace. At high temperature these vapours or molten scale have deleterious effect on refractories and corrosion of working lining particularly in the charging end takes place. Mitra et al[7] studied the nature of corrosion of H. A. bricks with reheating furnace slags. They pointed out that matrix containing cristobalite and glass is preferentially attacked by iron rich slags with the formation of low melting compounds such as fayalite, $2\,FeO.SiO_2$ and refractories are corroded by the diffusion of Fe^{++} ion under reducing atmosphere prevailing in the furnace. It has been noticed that some amount of iron oxide are absorbed on brick surface and hot faces of bricks show shrinkages. The result is spalling of bricks due to differential stresses developed by changed structure[8]. Fig 5 shows an example of rapid wear of 60% alumina bricks after 6 weeks of operation in the cover of C. W. mill furnace.

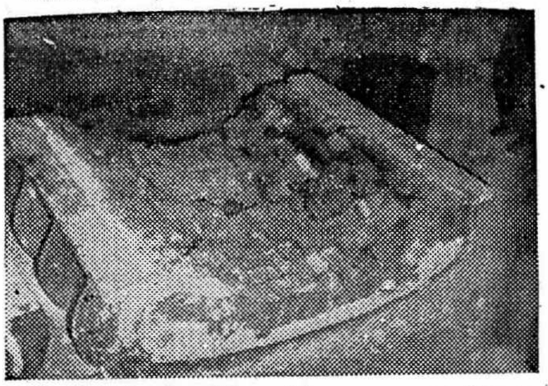

Fig 5 Condition of furnace cover after 4 weeks of campaign.

Considering the foregoing discussion it can be said that due to severity of operation in C. W. mill furnace, refractories must posses following properties :

i) High thermal shock resistance

ii) Minimum attack by iron rich slag and

iii) Good volume stability

In USSR for pipe welding furnace 62% alumina brick is used [9a]. Recently utilization of 62% alumina brick conforming to GOST BRO 62 from indigenous source has been taken up for sidewalls and furnace covers. Initial results have shown that better life can be obtained by using these bricks. The reasons for such success can be attributed to good spall resistance and less attack by slag rich with iron.

The present trend, particularly in USA and other western countries, is to replace shaped bricks with fully monolithic construction installed in situ or use large precast blocks[10, 11]. Besides good thermal shock resistance, use of such refractories have the advantage of inherent lower conductivity over equivalent grade of dense brick. With this view in mind, work is in progress in I. T. C. to use high alumina base refractory castable with metallic anchors for furnace covers (roof). The properties of the castable under evaluation is given below :

Recommended service temperature	...	1600 °C
Cold crushing strength Kg/cm²	...	300
Permanent linear change (1500 °C)	...	+ 0.5
Thermal conductivity (500°C mean) BTU. in/ft²/h/°F	...	6.6
Refractoriness	...	1750 °C

Burner block

As in sidewall, at present 60% alumina brick is also used for burner block. Refractories in this area are subjected to the destructive influence of rapid heating and cooling as well as severe over heating due to radiation and flame impingement During operation, slag build up is frequently encountered which tend to effect the direction of flames. Fig. 6 shows the condition of side wall in No. 4 Section of a C. W. mill furnace after 8 weeks of operation. It has been observed that burner blocks first get cracked and damaged, causing the subsequent layer above it weak. So whenever few burner blocks get damaged, refractory structure in the vicinity also wear out

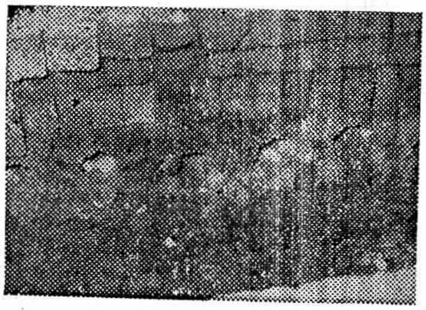

Fig. 6 Condition of furnace sidewall after 4 weeks of service

rapidly. Applegate[12] reported that burner block made from mullite grain and formed by tamping when wet into a mould with an air ram gave successful results. In I. T. C., we tried H. A. castable block (application temperature 1500 °C; C. C. S.—200 kg/cm²; P. L. C.—(1500 °C/5 hrs) ± 1%, refractoriness—(over 1700 °C) for burner block and initial results were very encouraging. Some of these cast-blocks were strengthened with S. S. 310 stainless steel fibres to see the extent of resistance to spalling. So far first trial was successful and details may be communicated later on.

As regards selection of refractories concerned, it can be said that best quality mullite brick is most suitable for No. 3 and 4 sections where service conditions are most severe However, cost of this brick in India is 5 to 6 times higher than conventional 60% H. A. brick and this is the reason why economic feasibility for former brick is not attractive.

General conditions of operation and heat transfer

Economy of F. M. continuous tube welding process rest on its speed. The extent of this speed depends on the size and gauge of the skelp being rolled. Various sizes of the skelp used in F. M. manufacturing process at I.T.C. and their relationship with rolling speed are shown in Table III.

Primary function of the continuous welding mill furnace is to heat the skelp to welding temperature in minimum time with minimum fuel consumption. To meet these objectives the first requirement is that the rate of heat transfer from the furnace to the skelp should be as high as possible and second, the heating capacity of the furnace should be utilized to the optimum value.

Co-efficient of heat transfer, which also determine the heating capacity of a furnace is function of many variables, most important of which are :

i) Final temperature of stock

ii) Average operating temperature of the furnace

iii) Emissivity of the stock

iv) Ratio 'R' of exposed surface area of the stock to the total interior area of the refractory.

Highest possible heat transfer from a furnace is obtained by maintaining the temperature of the heating zone as high as possible (without damage to the stock) with high velocity of flow of gases and maintaining 'R' value less than 0.25. In C. W. mill furnace, these conditions are achieved by closed space side firing with high velocity burner and keeping gas travel short by withdrawing hot gases at centre with 0.02% wg. draught.

Rate of heat transfer by convection, q_c from gases to the stock is given by[13, 14] :

$$q_c = A_s h_c (T_g - T_s) \quad \text{...} \quad (1)$$

Where A_s =area of stock, T_s =stock surface temperature, T_g =Temperature of furnace gas, h_c = Convective heat transfer coefficient which is a direct function of mass velocity [5b]. Calculation of convective heat transfer coefficient is explained in various publications[15].

The radiative heat transfer rate, q_w from refractory walls to stock surface in a furnace is given by[14] :

$$q_w = \sigma A_w F_{ws} (T_w)^4 \quad \text{...} \quad (2)$$

TABLE—III Relationship of skelp sizes with rolling speed

Size of tube n. b.	Width of skelp	Thickness of skelp	Speed of movement	Residence time in the furnace
Inch	Inch	Inch	f. p. m.	minutes
1/2	3.0	0.104	480	0.270
3/4	3.8	0.116	400	0.325
1	4 75	0.128	300	0.433
1.1/4	6.00	0.144	260	0.500
1.1/2	6.80	0.160	230	0.565
2	8.50	0.160	190	0 684
2.1/2	10.50	0.176	160	0.812
3	12.25	0:176	120	1.080

Where σ = Stefan— Boltzman constant, A_W = area of the walls, T_W = temperature of wall, F_{ws} = a factor which represents the fraction of radiation leaving walls that is intercepted by stock surface (values can be found in literatures[9c, 16, 17])

The radiative heat transfer rate from the flames (or furnace gases) which is absorbed by the stock is given below :

$$a_s q_g = a_s A_s \sigma (\varepsilon_g T_g{}^4) \quad \ldots \quad (3)$$

where a_s = absorptivity of stock surface. ε_g = emissivity of gas for non-luminous flames.

The stock itself emits radiation :

$$q_s = \sigma A_s \ \varepsilon_s (T_s{}^4) \quad \ldots \quad (4)$$

The overall heat transfer rate to the stock surface can hence be written as :

$$q = A_s h_c (T_g - T_s) + \sigma A_W F_{ws} (T_W)^4 + a_s A_s \sigma (\varepsilon_g T_g{}^4) - \sigma A_s \varepsilon_s (T_s)^4 \ldots (5)$$

where, ε_s = emissivity of stock.

The factor 'F' between two surfaces (equation 2), called view factor, represents the fraction of radiation flux leaving one surface which is transmitted directly into another; and for two surfaces in clear atmosphere, it is calculated by use of flux algebra in the following form[9b].

$$F = \int_{A_1}\int_{A_2} \frac{\cos \phi_1 \cos \phi_2}{\pi r^2} dA_1 . dA_2 \ldots (6)$$

where ϕ_1 and ϕ_2 = angles between the normal at the centre of elements of surface and direction of radiation flux.

A_1 and A_2 = surface areas of bodies 1 and 2 taking part in heat exchange.

r = distance between elements of areas dA_1 and dA_2

The above is schematically represented in Fig. 7. The relevation of equation 6 is that if two surfaces are opposed and close together then factor between them is high and direct radiation interchange is correspondingly high. If surfaces are arranged so that r and ϕ are large, direct interchange between them become small.

Advantage of above illustration is utilized in the design of C. W. mill furnace by making combustion chamber narrow and inside height of furnace relatively small. By this arrangement, 'F' which for a furnace of height 4 ft.

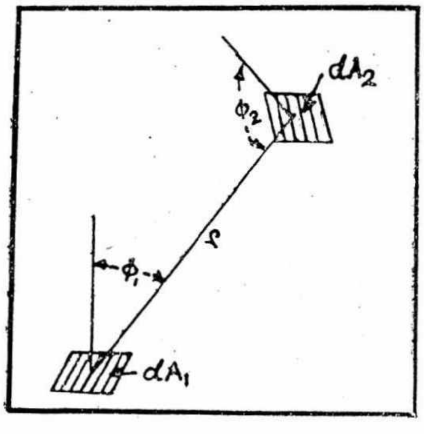

Fig. 7 Showing radiation exchange between two small surface elements; dA_1 and dA_2 located on A_1 and A_2

works to 0.37 becomes 0.6 with 2 ft. height[9c]. Therefore direct radiation consequently increases from 37% to 60%. Actually the effective working height in our C. W. mill furnace is 2 ft.

Having considered in general, the parameters controlling the heating of steel in furnaces, let us consider the heating process of skelp. The skelp, as it enters the furnace through door guides, burners direct the hot gases at high velocity on to the skelp edges. These gases not only heat the skelp by direct contact but also remove stagnant layer of gaseous films which stay on the surface of skelp and offer resistance to heat transfer. Reduction of thickness of this layer improves the heat transfer rate and reduce heating time. Therefore, to increase the heat transfer by convection in C. W. mill furnace, it is necessary to force the combustion products over the skelp at as high velocity as practicable. The type of furnace described here requires a very high heat release rate combustion system, one of the highest in the industry[4].

Fig 8 gives the temperature profile for our furnace and data of this is based on readings for a period of 3 months. In order to obtain less scattering in any portion of the curve, care must be taken for proper operation of burners in various zones. Incorrect proportion of fuel : air in any individual zone can lead to lower fuel efficiency of the furnace. Thermal efficiencies of C. W. mill varies from 15—20%, depending on size of tubes rolled,

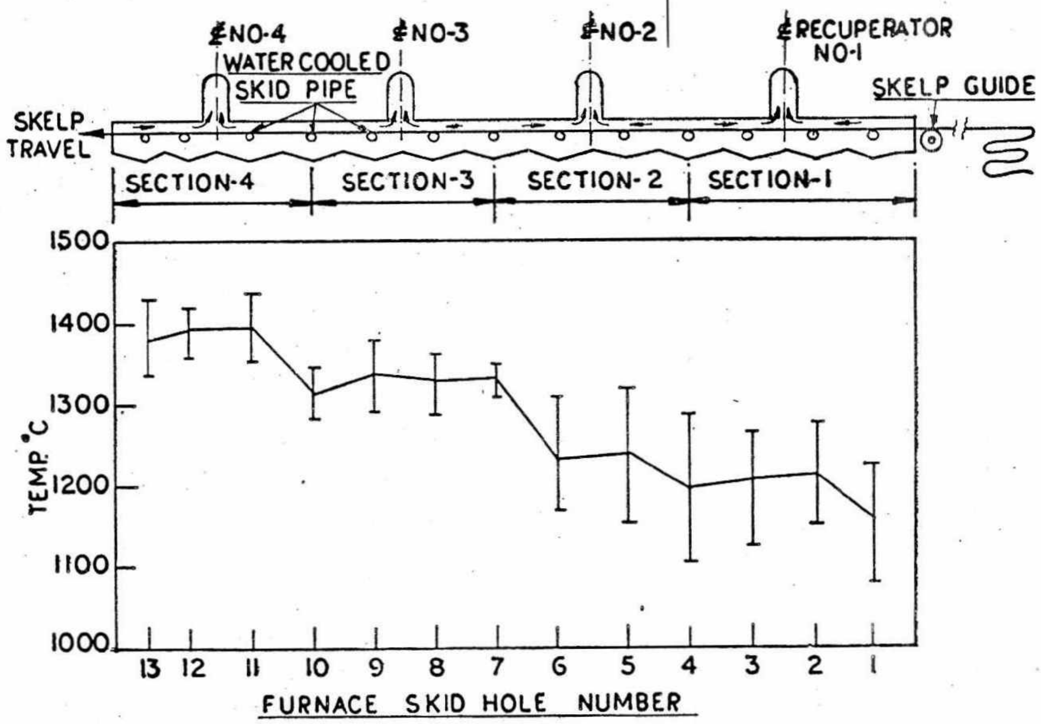

Fig. 8 Variation of furnace temperature at various zones

type of burners and preheating temperature of skelp, etc.

In I. T. C. preheating of skelp has been tried and maximum temperature so far obtained was 425 °C. In U. K. and other countries preheating temperature generally range from 450—500 °C. This gives higher output of mill by 15%[6].

Conclusion

Considering the design aspects and operational practice of existing furnace in I. T. C., it may be concluded that there are further scope for improvement, some of which are mentioned below :

i) Use of high velocity burner to increase production and lower energy consumption.

ii) Preheating of skelp to 450-500°C as a regular basis for 1st and 2nd zones to get higher output and lower energy consumption.

iii) Enrichment of combustion air with oxygen (3—5%) for improvement of furnace efficiency.

iv) Developing some methods for removing slag during hot condition. This helps in effective utilization of combustion space and also enhance refractory life.

v) Use of monolithic construction and application of metal fibre reinforced high alumina (75%)

monoliths should be tried to get longer refractory life. Also gunning of sidewall and uptake boxes should be practiced to reduce refractory consumption.

vi) Avoid rapid heating and cooling of furnace as far as practicable. This will prolong refractory life.

vii) Use of refractory coating over water cooled skid pipe to reduce heat loss and increase the life of pipe.

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References

1. H. CHAKRAVARTY, "Steel Tube Industry" pp. II. a supplement of the Statesman, 28th August 1976.

2. ANON, "Screw and Socketed Tubes", Indian Tube Co Ltd

3. J. THOMSON, "Manufacture of Fretz-Moon-Tube" Tisco Tech. J. 6, 299-310 (1959).

4. G. J. CAMPBELL, "Use of High Velocity Burners for Edge Heating Skelp" Iron and Steel Engg. 111—116 (1954).

5.a W. TRINKS & M. H. MAWHINNEY, "Industrial Furnace, Vol. 1, 201, 5th ed. John Willey and Sons Inc. (1961).

b ibid, pp 32.

6. Private Communication with C. H. A. Boyse, British Steel Corporation, Tube Division, U. K.

7. S. K. MITRA, et al "Study on slag corrosion of high alumina refractories" 86—94, proceeding of seminar on high alumina refractories, IRMA, Calcutta (1973)

8. T. N. VERMA, et al "Experiences with high alumina refractories in Tisco" Ibid pp. 152—162

9.a E. I. KAZANTSEV, pp. 135, Industrial Furnaces, MIR, Moscow (1977).

b Ibid, pp. 293

c Ibid, pp. 304

10. R. L. WESSEL, "Selection and use of refractory concretes in the steel plant" Symposium on refractory concrete, Am Concr. Inst. Mar, (1977).

11. Feuerfeste plastics, Institute Der Feuerfest, Industrie Meissen, 825 Meissen, Brauhausstrasse, 21 DDR.

12. Applegate. E. L. 138, Tube Mill Practice, Assn. Iron & Steel Engg., Pittsburgh, USA (1953).

13. F. FITZERALD & J. R. LAKIN, "Refractory and heat transfer In furnaces" J. Inst. Fuel 45, 380, 549, (1972).

14. DRYDEN, I. G. C. ed. Efficient use of Energy, 118, IPC, Science and Technology Press, U. K. (1975).

15. A. SHACK, Industrial heat transfer, Chapman and Hall, London, (1965).

16. W. H. Mc ADAMS, "Heat Transmission," 3rd ed., Mc Graw Hill, London, (1954).

17. R. H. PERRY & C. H. CHITTON, Chemical Engineer's Hand Book, 5th ed., Mc Graw-Hill, N. Y. 1973.