Reheating furnace's soaking zone hearth refractories—a rational approach

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The technology of steel processing subsequent to ingot casting, follows heating in soaking pit and rolling to form blooms, billets etc. Further reduction is carried out through heating and rolling to yield the final usable products. Reheating furnaces are used in reheating the "Semis" before they are used in secondary-processing.

In principle a reheating furnace is one which supplies the desired quantum of heat energy required to develop the necessary workability to facilitate further shaping of steel. It is designed to achieve a specific temperature, above the recrystallization temp. of metal, in a stipulated period and to allow necessary soaking for temperature homogenisation. To ensure satisfactory hot working the temperature may range from 1050 to 1350 °C.

Reheat furnace in Indian plants

The shape and size of reheat furnaces vary with charge, temperature, output, etc. In India the units range in capacity from 70 to 260 T per hour and the operating temperature varies from

This paper embraces the problems encountered and various developmental inputs in the soaking zone hearth of Indian steel plants. An attempt has been made to analyse the basic parameters of the problem and to define the characteristics of the desired refractories. A techno-economic appraisal for application of electrocast blocks replacing conventional practice of skid and paving is also included.

1250 °C to 1350 °C. They are multizonal, normally mixed gas (coke oven_ blast furnace) fired and provided with heat recuperator or regenerator. The units, both end or side-discharging, are either walking beam type or pusher type having stationery hearths with top and bottom burners.

Problems of reheating furnaces

In a reheating furnace (pusher type) the severity of operational conditions increases in the direction of charge-movement and maximises in soaking zone. In the side-discharge units, the ejection out of the charge introduces additional abrasion on the paving. The

operational hazards are : Impact which follows drop of piled up charge, frequent cooling for maintenance resulting in thermal stresses, excess abrasion etc. Mechanical abrasion accentuated by the presence of scales at an elevated temperature, is however, the main problem in the soaking zone hearth.

The scale generated amounting upto 2% of charge weight, is also a negative contributor to the furnace performance. The surface oxidation leading to scale formation and decarburisation is insignificant below 700 °C and proceeds rapidly particularly at temperatures above 1050 °C[1,2]. The scales can be of various types like coherent, layered, porous and transversely cracked[3]. As temperature rises it sinters, fuses and even melts if the temperature has increased excessively or due to increase in Si, Mn content. The scale reacts with the refractory and slowly builds up hindering movement and necessitating frequent cooling of the furnace.

Possibly the most detrimental contributor is the metallic skids. The worn out or damaged skid results in overloading of pusher, mechanical misalignments, damage to refractory hearth etc. The net result is shut downs and fall in plant-productivity. In addition, it affects considerably the thermal efficiency of the unit. In fact, skid affects adversly the cost associated with capital, maintenance and running besides output of quality product, either directly or indirectly.

Metal skids and its limitations

In a reheating furnace metallic skids are provided to facilitate movement of the material. They are laid on a refractory paving. The skid is built in two parts, it is water cooled in preheating and heating zone whilst no cooling is provided in the soaking zone. The commonly used material is heat resistant steel of various grades. A few compositions are given in Table I.

The skid systems consume a large amount of heat generated in the furnace and has a major impact on the thermal balance. To illustrate its impact on fuel efficiency it may be mentioned that a 3-zone furnace is reported to have a thermal efficiency two-thirds of that of a 2-zone unit, which is primarily attributed to the skid system. (Table II·)

In larger units skid surface can be upto 260m² resulting in loss upto 25% of heat input[4].

The skid system extracts heat from the heated charge and casts radiation shadow and produces cold spots known as 'skid mark'. The latter affects subsequent rolling and quality of steel and even may be the cause of high rejection. In addition, it narrows down the usable 'drop-out' temperature band and increases the possibility of over or under-heating of charge. If temperature is increased to compensate for skid-mark or to push the furnace harder, the fuel consumption and the amount of scale increases and subsequent melting of scales brings down the life of the hearth.

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TABLE—I Composition of skid

Composition	I	II	III
Cr—%	28	24/28	22—25
Sn—%	—	1/1.5	—
Mn—%	0.80	0.52	—
Ni—%	0.6	—	45—48
W—%	—	—	5

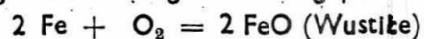**TABLE—II Pusher furnace effeciencies**
(Following Laws 4)

Furnace type	Throughput tonnes/hr	Thermal Efficiency
I Zone	40	60
2 Zone	90	55
3 Zone	120	37
5 Zone	200	27

Scale-its origin and contribution

Refractory problem is very often simply one of liquid development, which is the most important of the several causes of failure of a refractory during use. The amount and the nature of the scale formed is also of vital importance in determining the life of the soaking zone hearth refractories.

The scale is an oxidation product of metallic iron and in reheating furnaces where the charge is moving at an elevated temperature and under very low partial pressure of oxygen (only 2—3% excess oxygen in the flue), the following reactions might be taking place :
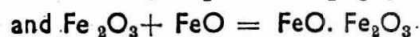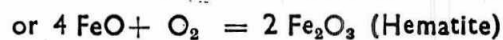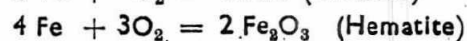
$$2\,Fe + O_2 = 2\,FeO \text{ (Wustite)}$$
$$4\,Fe + 3O_2 = 2\,Fe_2O_3 \text{ (Hematite)}$$
or $4\,FeO + O_2 = 2\,Fe_2O_3$ (Hematite)
and $Fe_2O_3 + FeO = FeO.\,Fe_2O_3$
(Magnetite)

The rate and degree of the above reactions, however, depend on various factors like time of gas-solid contact, temperature, available oxygen, etc.

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In a reheating furnace as the stock is moving, fresh surfaces of metallic iron are readily accessible to the oxidant and from Table III, it may be observed thermodynamically that formation of FeO from Fe is preferred rather than that of Fe_2O_3 from FeO, where both the possibilities co-exist. Secondly, with a very low partial pressure of oxygen and a huge exposed surface of the reductant, preferential formation of FeO is envisaged. Lastly the scales forming on and sticking to the surface of the charge will mainly be FeO rather than Fe_2O_3, possibly for the reducing effect of CO, formed due to surface decarburization Though it may be envisaged that the amount of FeO in the scale will be more, the high temperature and presence of oxygen, however, are imperative for the formation of Fe_2O_3 and the formation of FeO. Fe_2O_3, is also highly probable.

So in reality the scales of a reheating furnace generally consist of a mixture of FeO, Fe_2O_3 and Fe_3O_4 (FeO. Fe_2O_3), the relative amount varying mainly with the conditions prevailing in a particular furnace. However, it may be pointed out that the scale as found, is generally a mixture of 65% FeO and 35% Fe_2O_3 approximately. The analysis of reheating furnace scale from TISCO[5] may be referred in this context.

FeO	61.66%
Fe_2O_3	32.32
MnO	1.08
Others	Rest

It will also be found from the FeO.Fe_2O_3 phase relations (Fig. A), based mainly on data of Darken and Gurry[6] that a scale having the above composition and at the operating temperature of reheating furnaces (1280—1320°C) will have Wustite as the major stable phase.

The reaction of FeO with high alumina refractories thus becomes the determining factor as far as corrosion is concerned. High alumina refractories contain either mullite and silica (as cristobalite/tridynite) or corundum and mullite as the final phase depending on the Al_2O_3 content.

Two of the crystalline phases generally present in alumina silica refractories, mullite and corundum can accommodate iron ions in their lattices, but only in ferric state ($Fe+3$.) Where the iron oxide is present as FeO, a substitution of this element in the crystal lattice is not possible[7] and hence even a small amount of iron oxide absorbed causes a liquid to develop at temperatures above 1210 or 1380°C (as shown in Fig. B) depending on the original crystalline phase present in the brick, and ultimately leads to failure.

Liquid formation in chrome refractories is, however, not generally the only cause of their failure. The usual "bursting expansion" accompanying iron oxide absorption by the spinel grains of a chrome.body seems to play also an important role in its failure. When iron oxide goes into solid solution in the spinel, swelling occurs as the porosity is increased. Rigby[8] believes that this-growth is due to the

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TABLE—III Thermodynamic data of Iron oxides & Silicate

	Molecular weight	Melting point °C	Entropy S°_{25} (Cal/°C mole)	Reaction	Temp. T °C	Enthalpy of formation H°_T (Cal/mole)	Entropy of formation S°_T (Cal/mole)	Free Enthalpy G°_T (Cal/mole)	Heat of Melting Cal/mole
FeO (Wustite)	71.85	1377	13.54	$0.95\,Fe + 1/2\,O_2 = Fe_{0.95}O$	25	−63700	−17.6	−58400	7490
					1027	−63100	—	−42900	
					1127	−62900	—	−41400	
Fe_3O_4 (Magnetite)	231.55	1597	35.0	$3\,Fe + 2O_2 = Fe_3O_4$	25	−267000	−82.5	−242420	3300
					1027	−260600	—	−167400	
					1127	−260100	—	−160300	
Fe_2O_3 (Hematite)	159.70	1536	21.5	$2Fe + 3/2\,O_2 = Fe_2O_3$	25	−196500	65.0	−177140	3700
					1027	−192300	—	−116400	
					1127	−191900	—	−110600	
Fe_2SiO_4	203.76	1217	34.5	$2\,FeO + SiO_2 = Fe_2SiO_4$	25	−10900	−1.4	−10480	22030
					1127	−8625	—	−1610	

L. Von Bogdandy. H.—S. Engell—The reduction of Iron Ores, Scientific Basis and Technology 1971. Springer—Verlag. Berlin, Heidelberg, New York.

G°_T molar free enthalpy at P = 1 atm. and T °C.
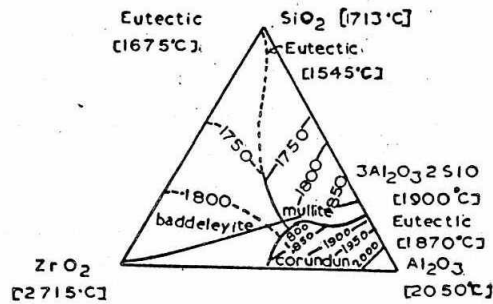H°_T molar free enthalpy at P = 1 atm. and T °C.

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FIG.B: The system $ZrO_2 - Al_2O_3 - SiO_2$
(after Budnikov and litvakovskii)

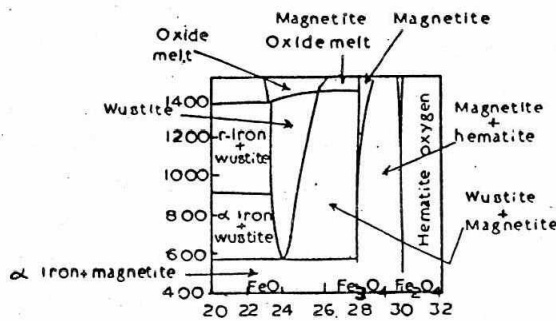FIG. A Iron oxygen system (section)
(Based on data of Darken & Gurry, Phillips & Maun & Maun)
Ref Reduction of Iron ores — L van Bagdandy p ·971,P·18

difference in duffusion rates among the ions. Chrome-magnesite refractories, however, have certain advantages over the straight chrome bricks. Chrome magnesite bricks after firing are constituted essentially of three phases. Periclase, chrome-spinel and forsterite (sometimes monticellite). These bricks have much greater refractoriness and less tendency towards "bursting" as iron oxide is absorbed but they, however, spall, peel or disintegrate, where the environment is conducive to iron oxide effects.

Measures to improve furnace performance

The performance of a reheating furnace can be improved by adopting one of following measures in the soaking zone :

i) Improving the metallic skid sytem

ii) Introduction of refractory skids

iii) Replacing skids with solid-hearth

The effects of metallic skid have been investigated extensively by many authors [9,10,11] with the objective to reduce skid-mark and improve heat utilisation. The design suggested by Salter[11], provides optimum utilisation of heat resistant special seel while minimising radiation shadows. It is a triangular skid with a hot UMCO 50 type wearer bar with minimum surface area of contact and insulated with refrac-

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tory (Fig. C). However, the full benefits of this hot-skid is still to be established.

The application of refractory skid has been successfully tried out in operation. The skid consists of electro-cast blocks of various sizes and shapes. The basic constituents of the matrix are corundum, mullite and occasionally zircon. These products have better abrasion and hot-load properties than metallic skid besides having good re-

Minimum shadowing skid - Logic

Triangular hot skid

FIG. C

sistance to erosion, its most beneficial contribution being elimination of skid mark. It extracts little heat from the charge, consequently improves the thermal efficiency af the furnace. It is not wetted by the slag resulting a self-cleaning surface. Further, it does not deform and does no injury to either the furnace mechanism or the refractory lining and as a result the furnace campaign-life increases.

The solid-hearth design provides a flat refractory paving of electro-cast refractory blocks of large dimensions to minimise joints and needs no skid of either type. Application of monolithic mass of high-alumina and basic compositions are also mentioned. In this design the charge gets heated only from the top and has no risk of skid-mark.

Refractories requirement for soaking zone

From the study of the reactions of scale with the underlying refractories it appears that the mechanism of attack involves diffusion followed by formation of eutectic with glassy matrix and its subsequent migration dissolving the crystals on its way. However, if the scale is in molten stage, due to excessively high temperature and intake of Si from steel, the above reactions will become much more severe. The reacted-zone of the refractory surface forms a jointless mass with the overlying scale and may get removed with the scale while the latter is being scrapped. In addition, resistance to abrasion at high temperature is also a pre-condition for a quality refractory.
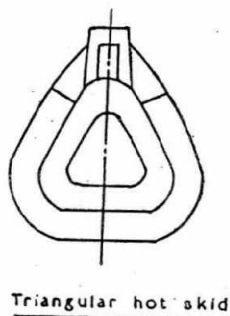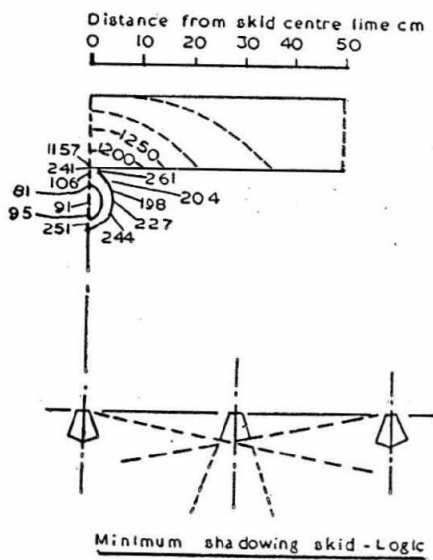
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The soaking zone requirements stress on a few specific properties for refractory like :

1. High abrasion resistance at 1000-1300 °C.

2. Low wetting-angle with scale.

3. High resistance to penetration of scale.

4. Low content and high liquidus temp. of vitreous phase.

5. High mechanical strength at 1000-1300 °C.

6. Low linear expansion

7. High volume stability upto 1300 °C.

The properties 2, 3 & 4 are to counteract corrosion whereas 1 & 5 are required to meet mechanical impact and dragging forces respectively. The low expansion is desired to meet sudden fluctuation of temperature and joint opening up is avoided by having good volume stability. These qualities can be achieved through measures taken in the following areas during production of refractories viz :

1. Texture—homogeneous with lowest porosity.

2. Pores—sealed and finer to restrict liquid flow.

3. Matrix—optimum glass to develop mechanical properties.

4. Phases—crystalline & interwoven.

5. Constituents—highly refractory and non-wetting by slag.

Electro-cast vs bonded refractories

The sintered or fused-grain rebonded refractories may meet the above requirements to a considerable extent However, the electrocast technology, fortunately provides the maximum scope to attain the specified goals.

In the technology for bonded refractories the sintering and fusion reactions are normally arrested at a level, enough to provide the desired ceramic bond, whereas it is unarrested in electro-cast technology allowing full crystallization or formation of solid solution in vitreous matrix. The subsequent controlled cooling assists further growth of crystals also to release internal stresses. In previous case the crystal growth is limited in the grain or on the boundary-zone only.

The grain-bonded products possess pores of various nature (spherical/ elongated, linked / sealed large / small) and amount. It may even be distributed irregularly, providing a heterogeneous pore-texture. These variations can be reduced to a considerable extent but can never be eliminated. Whereas the electro-cast technology offers a texture almost devoid of pores eliminating its detrimental effects and also gives rise to a homogeneous texture. Further the vitreous matrix is heavily laden with crystals, which results in better physical and pyro-physical characteristics. In addition, the glassy matrix being a homogeneous mass,

possesses more resistance to pyro-chemical reactivities and their intensities. The previous products have a glassy matrix more concentrated in fluxes located in the bond region which allows faster eating away by slag and floating of grains in the resulted low temperature eutectics. This results in uneffective utilisation of the superior refractory components.

It is evident that presence of vitreous mass, which normally is not desired in a grain-bonded refractory, becomes a useful component in the other process. It attributes, directly or indirectly, to lower slag-penetration and restricted erosion, better pyro-physical and chemical properties of electrocast products. However, its amount and nature influences, as evident, its thermal spalling behaviour.

A close look at the reheating furnaces conditions reveals that the refractory scale interface is practically sealed off from the furnace atmosphere which normally holds 2—3% free oxygen. Further, the over lying scale is a heterogeneous mix of oxides of iron, predominently being FeO. The oxygen having higher preference for Fe (low heat of formation) produces the low potential oxide—FeO rather than

FeO Fe_2O_3 or Fe_2O_3 from FeO
as discussed earlier.

The furnace temperature when prevails in a range such that the scale-refractory interface being restricted to say 1200 °C, the liquid eutectic or molten scale will not penetrate much as compared to when the temperature is higher say, around 1250 °C, for obvious reasons. The atmosphere if reducing, promotes formation of the eutectic which accelerates the attack Also the deeper the penetration the stronger may be the bond with the fuses scale, which results in easy removal of refractory while cleaning the scale. The electro-cast products being devoid of open pores and having vitreous refractory matrix restricts the attack to surface-skin which results in easy removal of scale with minimum damage to the hearth paving.

The electrocast refractories include systems like mono-components (alumina, magnesia) binary compositions (alumino-silicates, basic spinels—MgO Cr_2O_3, MgO. Al_2O_3) and multi-components (alumina-silica zirconia). However, the qualities generally considered suitable for reheat furnace soaking zone are alumino-silicates with or without zirconia and alumina alone.

Why Al_2O_3—ZrO_2 fusion cast

Comparatively few of the phase diagrams of the oxide systems containing zirconia have been evaluated. One of the most important phase diagrams, Al_2O_3—ZrO_2—SiO_2, was first published by Budnikov & Litvakovskii in 1965. An eutectic was found with the composition 53% Al_2O_3, 17% SiO_2 and 30% ZrO_2, melting at 1800 °C.

Al_2O_3- ZrO_2 however, forms a simple eutectic system that has very limited solid solution at high temperatures. Fusion cast alumina-zirconia refractories are superior to fusion cast alumina refractories because pure alumina on

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fusion and subsequent cooling, crystallises in a columnar structure and voids form between the columnar crystals, these are primarily due to shrinkage that occurs when molten alumina solidifies.

Materials with these type of structure are very weak (modulus of rupture below 1000 psi) and have very poor thermal shock resistance, but when ZrO_2 is added to Al_2O_3, the structure becomes equiaxial. The finely divided entectic structure gives these fusion cast materials their high impact strength and toughness which permits their use in places, where abrasion is very high[12].

Refractories status in Indian plants

The Indian steel plants are practising the conventional metallic skid-refractory paving and have recently introduced the solid hearth without skids in the soaking zone of reheating furnaces. The qualities tried and being used for paving includes the grainbonded alumino-silicates (60—80% Al_2O_3) basic spinels (chrome-magnesite), monolithics (high alumina and chrome mixes) and electro cast (mullite-corundum-zircon) products. A grain bonded high alumina indigeneous product has been giving encouraging result at one plant whereas the same has not been found satisfactory at another plant, the possible reason being temperature associated with nature of charge. The electro-cast products has been performing satisfactorily at one plant in the paving. A solid-hearth using electro-cast corundum block has been introduced and is performing satisfactorily. An extensive review has been produced recently[13]

Electro - cast refractories— A techno-economic picture

It may be realised that the electrocast refractories appears to be the ultimate solution to meet the most stringent requirements of the soaking zone hearth of a reheat furnace. But the viability has also to be examined in the light of the economics before switching over to all-refractory hearths. The experience abroad infers that bennfits can be obtained at significantly reduced cost if the materials are used in the form of skids either flush or producing[1]. However an attempt has been made to evaluate the prospects in the country. It reveals after conducting a comparative cost benefit analysis (Table IV·) based on broad informations that an electro-cast have positive prospects in our plants replacing the metallic skids and the conventional rebonded refractories in the soaking zone of reheat furnaces. The only draw back being the high capital cost, which however is compensated due to increased availability of the furnaces alone. The economics will be more attractive since actual life of such hearths is more than two years which is the assumption of the estimation.

TABLE—IV Properties of a few refractories for soaking zone hearth

Properties	Indigenous grain bonded				Imported grain bonded		Imported fusion cast				
	I	II	III	IV	I	II	I	II	III	IV	V
Al_2O_3 %	—	85 min	92 ± 1	87.0	83.4	85.8 to 88.2	74.0 +ZrO_2 4—5%	99.6	70—71.0 ZrO_2 —26.0	90—95	78.43
Cr_2O_3 %	18.0	—	—	—	—	—	—	—	—	—	—
MgO %	80.0	—	—	—	0.3(+CaO)	0.5 (CaO)	CaO—0.4	CaO—0.05	—	—	0.05
TiO_2 %	—	—	1.0 max	—	2.7	2.4—3.0	0.4	0.008	2.40	0.5	2.10
SiO_2 %	—	—	3.0 max	—	11.5	6.6—9.5	19—20	0.1	0.70	2.5	16 31
Fe_2O_3 %	—	—	0.5 max	—	1.6	1.5—2.4	0.6	0.02	0.50	0.7	3.01
P. C. E	—	SK 36	SK 36	—	38 (1850°C)	39—40	—	2050°C	1925°C	1950°C	—
App. porosity %	24.0 max	16.0 max	22.0 max	16.0 max	23.8	17 to 21	—	—	—	2—3%	2% max
C C. S. Kg/cm_2	250 min	800 min	600 min	900 min	800	570	2000	—	—	—	—
R. U. L. ta°C	1600	1450 min	1650 min	—	—	1550	1770	—	1700	—	—
Abradibility Index	—	15—25	5—15	20—30	120	—	—	—	—	—	—
Morgan-Marshall B. D., g/cc	—	—	—	—	2.67	2.82—2.97	3.00	3.92	4.36	3.00	3.05
App. Solid Density, g/cc	—	—	—	—	—	—	3.38	—	—	—	3.32

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TABLE—V

Comparative cost benefit analysis

Capacity of the furnace	:	100 T/hr
Soaking zone hearth dimen	:	high chromium steel skids & chrome magnesite bricks

COST COMPARISON

Metallic skid & refractory (Cr—Mag)		Electro-cast solid hearth	
1. No. of skids	8	Tonnage of blocks (T)	30 approx.
2. Weight of each skid	1.1 T	Cost per tonne (Rs.)	10,000/-
3. Cost of skid (Rs/T)	11,000/-		
4. Total cost of skid (Rs)	96,800/-	Total cost (Rs.)	3 lakhs
5. Refractory tonnage	20 T	Life (Yrs)	Two
6. Cost of refractory (Rs)	40,000/-		
7. Total cost (skid+refrac.)	1,36,800/-		
8. Life (months)	8		
Annual cost (Rs)	2,05,200/-	Annual cost (Rs)	1,50,000/-
Saving in cost (materials) (Rs.)		Around 50,000 annually	
Saving of working days shut downs in days for every two yrs.	45		25
Saving (Operational) days	20 for every two years i. e. annually 10 days		

Advantages : Saving in cost (Rs.) 50,000/- per annum.
Saving in operational days 10 per annum,

(Refr.), for his valuable advice and guidance, to Dr. R. K. Iyengar, PC (SM & P) for his keen interest and to Dr S Ramachandran, GM (R & DC), for his permission to present this paper.

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