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Thermal Analysis of the Molten Lead Kettle Failure at the Galvanizing Plant and Development of Novel Design Using CFD Techniques

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ABSTRACT: The present work discusses problem of failure of kettle holding molten lead in a galvanizing plant. A CFD code Fluent was used to solve the problem using computational approach. The geometry is built in the GAMBIT environment and 3D solvers for turbulence, combustion and radiation heat transfer was applied. The study revealed the detection of the hot spot exactly at the same location of the kettle that was observed at the plant. This confirms the validity of the CFD Model. Based on this model the suggestions are made to overcome kettle bulging. For this two approaches are suggested. They are, differential heating of the kettle and the reduction in the width of the burner. The effect of both these alternatives is studied using a CFD model and the effectiveness of the results are discussed and compared using dimensionless surface parameter representing the temperature distribution and flue gas temperature.

Based on the results obtained an improvised geometry for the kettle heating is proposed. The proposed novel design has the following features:

- 50% reduction in the fuel consumption and lower start-up time.
- Separation of the zone of mechanical and thermal stresses and lower concentration of thermal stresses.
- Increase in the heat transfer area and a reduction in the heat losses through the exhaust.
- Reduction in the amount of lead used for the operation.

KEYWORDS: Galvanizing process, kettle failure, CFD code, pattern factor, kettle bulging.

I. INTRODUCTION

Galvanizing of steel is an energy intensive process and is carried out by passing of hot steel sheet in the pool of molten zinc. The sheet is cleaned prior to the galvanizing by allowing it to dip into the mixture of water and a cleaning agent (flux, which is ammonium chloride). Lead is used as a preheating agent and the sheet to be galvanized passes from the pool of molten lead before finally enter the molten pool of zinc. Molten pool of lead and zinc (in that order) is kept in the kettle. Fig. 1 shows the schematic of a galvanizing process. Due to the difference in the density, both the molten metal retain in the kettle as an immiscible. Molten zinc being light floats over the molten lead. A floating container, without having base is used to hold the molten zinc, so that the sheet may enter a pool of molten zinc from the bottom, after passing through (or after getting preheated) the pool of molten lead.

The kettle is heated from the outside, and is surrounded by four firing burners arranged on the vertical walls of the furnace surrounding the kettle. All four burners produce the flame front, and the path of flue gas takes a swirling motion in the counter clockwise direction, viewing from the top, surrounding to the walls of the kettle. The flue gases subsequently are allowed to pass to the chimney from the bottom of the kettle through a duct. It is observed that the entry of the sheet is inclined and the exit of the sheet is vertical. Such a path of sheet is maintained by an idler pulley immersed in the molten lead. It can also be observed that certain part of the kettle wall holding molten lead is emerging out of the furnace wall (above the ground level).

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The thermal energy input required for sustaining molten lead and zinc is transferred from the combustion products that travel in the furnace region. Four burners located as shown in Fig.1, allows the flame to propagate in the corridor of the furnace and the combustion products surrounding the kettle. The duct for the flue gas exhaust is at the bottom of the kettle base, which is followed by the chimney.

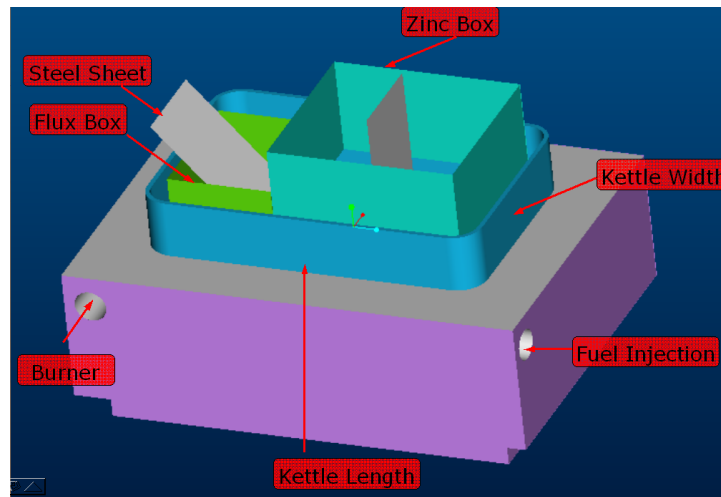


Fig. 1 Schematic of Galvanizing process

Production of the galvanized sheet is carried out on the continuous basis. Cold rolled MS sheet, wound over cylindrical mandrill with the axis of rotation horizontal with the feed rate of 32 m/min is the input for the galvanizing process. Fuel for the burners is Furnace oil (FO) or Light Diesel Oil (LDO). Presently the total fuel consumption for all four burners is of the order of 100 liters/hr. Since lead is preheating agent for the sheet, consumption of lead is negligible. However, zinc consumption for the production rate of the sheet mentioned above is 500 kg/hr. Mass of the lead and zinc available at any time for the galvanizing are 140 and 20-21 MT respectively. Inside dimensions of the kettle are 3700(l) x 2400(w) x 1800(h), and thickness of the kettle plate is 50 mm. 351 mm of the kettle wall height is projected to the ambient air.

II. REVIEW OF LITERATURE

Present section discusses the common issues that influence the galvanizing process and the current trend prevailing in the industry.

Basic galvanizing process consists of few important steps, e.g. soil and grease removal, fluxing, galvanizing and cooling. Under soil and grease removal stage a hot alkaline solution is used to remove dirt, oil, grease, shop oil, and soluble markings if any. Under pickling operation the dilute solutions of either hydrochloric or sulfuric acid is used to remove surface rust and mill scale to provide a chemically clean metallic surface. Next important aspect is fluxing. Under this the steel sheet is immersed in liquid flux (usually a zinc ammonium chloride solution) to remove oxides and to prevent oxidation prior to dipping into the molten lead bath. In the wet (continues) galvanizing process, the flux and zinc floats over the top of the molten lead. The steel sheet passes through the flux, molten lead and then finally enters in zinc box from the bottom for the galvanizing purpose. Third process is galvanizing. Under this the steel sheet is immersed in a bath of molten lead maintained at around temperature less than 500°C to preheating the sheet. The zinc temperature is observed between 455-472°C. During galvanizing, the zinc develops metallurgical bonds with the steel, creating a series of highly abrasion-resistant zinc-iron alloy layers, commonly topped by a layer of impact-resistant pure zinc. Final of all process is cooling of metallic sheet. This is carried out by subjecting galvanized sheet under the bath of air jet to reduce the temperature [7]

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Hot dip galvanising is the most popular method of corrosion protection. Under this the steel articles are immersed in molten zinc at 860 F (460°C) to form frozen metal on the surface. Drawbacks of this technique include the expense of heating parts at high temperature and generation of by-products such as zinc alloys, zinc oxides and smoke. Under recent policy the reduced acceptable lead levels in coating is recommended, since lead from galvanized coated steel may dissolve in the water. Such dissolved lead if consumed by human, may accumulate in human bodies with deleterious results. Another issue is the effect of molten salt layer on top of zinc (top flux) that causes kettle smoke and ash evolution, which are harmful to the human.

As an alternate to this lead free batch technology is recommended. The process used by ‘ThermoPrep’ is of such type. The process protects the steel surfaces with a thermally stable flux by preheating parts to 400 to 450 F (204–232°C) in separate furnace and then immersing them in molten lead free zinc for a short period of time. The use of thermally stable pre-flux would eliminate the need for top-flux which will reduce associated wastes. The proposed method has advantages like, 20-30% productivity increase with significant reduction in energy, top ash and smoke reduction, 15% coating thickness reduction to meet specification requirement, elimination of top-flux use on the kettle, ability to produce defect-free and lead-free zinc coating and increased kettle life [3].10-

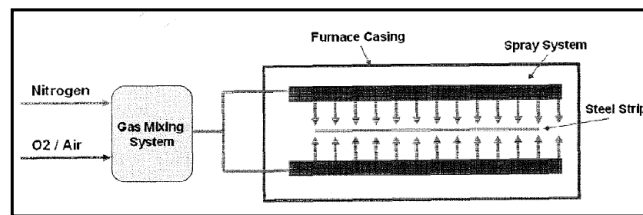


Fig. 2 Schematic of ThermoPrep process

The issue of oxidation of alloying element is a major concern while carrying out the galvanizing. New steel grades (referred as advanced high strength steels) with a very high yield point having a high elongation capacity have been developed over the years to meet the demands of higher safety and lower weight in the car industry. These steel raise some problems because some of the alloying elements such as manganese, silicon, aluminum, chromium may result in a thin layer of oxides on the steel surface during the annealing operation preceding the dipping in the galvanizing bath. This oxidation harms the zinc wettability and thus the quality of coating. The solution which is proposed is to subject the strip surface to temperature and atmosphere conditions fit for quickly and deeply oxidizing the alloy components in the direct fired furnace which is part of annealing furnace, thereby avoiding migration of oxidisable elements towards the surface followed by reducing the iron oxide back to iron in the radiant tube section. Then steel strip is dip in Hot dip galvanizing line where the oxygen content is 0.5 to 10%. The oxygen values above 10% the oxide layer did not have the desired composition and the growth rate of the oxide layer is too high resulting in thick oxide layers. At oxygen values below 0.5% the oxidation process was too slow and the oxide layer remained too thin. In a preferable embodiment the gas mixture comprises an oxygen content of between 2 to 4.5%. In an embodiment the oxidation of the steel strip surface or surfaces takes place between 650 °C and 900 °C.

The continuous hot dip galvanizing line is mainly dedicated to the production of galvanized corrugated & plain coils for the market. The process consists of 3 stages: metallurgical annealing, zinc coating deposition & temper rolling. Due to manual operation at zinc coating area, zinc consumption is higher & coating weight thickness is uncertain. Moreover, manual interventions, varying with the operative personnel, inevitably resulted in coating thickness fluctuations & out of range coatings. The parameters which affect the coating thickness over CR coil are identified and studied. The dependent variable, zinc coating weight is used as a measure of profitability. Relation between the dependent & independent variable helps in identifying the critical parameter or group of parameters which directly affects the process & ultimately final product. The current data recorded, examined & analysed for deciding the criticality of independent variables over the dependent one. A strong significant relationship between coating weight control & profitability has been found in previous empirical work. This research work is aimed at analysing the effect of process parameters on consumption of zinc in continuous galvanizing line thereby calculating the exact set of parameters to decide the actual coating thickness required [17]. The modern automobile requires the use of advanced high strength

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steels (AHSS). During annealing in the continuous annealing furnaces of hot-dip galvanizing lines, the alloying elements of AHSS form selective oxides. This can lead to undesirable quality defects during the coating process. The dewpoint control and the oxidation/reduction technique are key technologies for the hot-dip process of AHSS [16].

A dual-purpose production plant for cold rolled steel sheets and hot-dip galvanized steel sheets comprising, successively disposed in series is also found to have taken place. Such plants consist of a heating zone, a soaking zone, a primary cooling zone, an over-aging zone equipped with a controlled cooling facility, a molten galvanizing zone, an intermediate cooling means, a secondary cooling zone, a temper rolling means, and a chemical treatment means, and a bypass means for directly connecting over-aging zone and secondary cooling zone with each other. Another object is to provide a plant for producing deep drawing hot-dip galvanized steel sheets, particularly for car bodies, having zinc plating with good adhesive strength and having excellent performance characteristics as well as for producing galvanized steel sheets of high strength steel which is hardened by solid solution and dual-phase structure [18].

The flux-galvanizing process serves as a viable process for the continuous galvanizing of steel sheet. Although it has its own unique processing problems, such as the formation of flux fumes and flux ashes that need to be handled as waste products, it is a method of galvanizing that allows the construction of a galvanizing line without the expense of the typical large annealing furnace associated with the hydrogen cleaning method. For many producers of galvanized sheet, the annealing of steel sheet is an integral part of the complete steel processing procedure, and they incorporate the annealing furnace into the galvanizing line so that the hydrogen cleaning concept can be used. But, for those smaller manufacturers who want to purchase steel sheet and apply a zinc coating for corrosion protection, a flux galvanizing line is an alternative process – one that requires less capital expenditure [11].

Furnace burners are key component in galvanising. There are basically three types of furnaces or burners used in practice, flat flame burner, force circulation burners, high velocity burners. The plants mostly are found to have end firing type, the major advantage under this are, uniform kettle wear, better fuel efficiency and low maintenance, especially in case of the failure of the burner. With correctly designed furnace if the burner tube fails, the flame is directed along the gallery and not into kettle. Failure of flat flame burner and side wall mounted high velocity burners with a cranked firing tube can burn out the kettle in less than 48 hours, if the firing tubes fail or the flame pitched forward. The high velocity gas or oil-fueled burners are mounted into one or two diagonally opposite corners of a continuous gallery running 360 around kettle. The output momentum of the burners firing at upto 500 ft/sec causes a rapid recirculation of hot gases around the kettle producing high rates of heat transfer for all available points on the kettle. The bulk flow of the recirculating gases absorbs the intense local burner heat redistributing it evenly around the periphery of the kettle. This result in high operating efficiency and uniform heat transfer both around the kettle and over its depth leading to low uniform kettle wear [10].

When a gaseous fuel is mixed with air within its limits of flammability the mixture can be burned to release heat. Only 90% of the heat is usefully available. The rest 10 % of the heat can be attributed to either heat lost in production of steam in the products of combustion, heat loss through the furnace insulation, heat lost in heating kettle or Heat lost with flue gases from the furnace [10].

It is essential to account for the system efficiency for the galvanising plant. The system efficiency is defined as the gross heat input which is transferred from the combustion products as they pass through the furnace. The system efficiency can be derived as a function of the volume of the excess air used in combustion and of the temperature of the flue gases upon the exiting the furnace. Complete combustion of the fuel cannot be achieved with less than 0% excess air. Another limitation is if the zinc temperature is 840 F (450⁰C) than the flue gas temperature should be more than 840 F (450⁰C). From this parameters maximum theoretical system efficiency for a furnace operating on natural gas is 74% [10]. The energy efficiency of a galvanizing furnace can be presented in the form of set of equations. These equations can be non-dimensionalized to provide a description of furnace efficiency. Equations of this form can be used for comparing furnaces of different designs and fuel types in a completely objective fashion. This removes the reliance on production rates, which have characterized previous work on furnace energy consumption. The technique most commonly used to reduce energy consumption in galvanizing furnaces is to increase burner turndown [6].

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Wear of kettle is most crucial issue while deciding the operational issues of the galvanizing plant. In heating galvanizing baths, temperature uniformity is of prime importance, as these evens out the wear rates at different parts of the kettle and gives longer life. Temperature Uniformity is best achieved by the convective heat transfer, which results from circulating hot gases around the bath at a high speed. As the gas speed increases so the temperature of the gas required for heat transfer falls. Lower as temperatures give less storage of residual heat, better control and lower case losses as well as enabling more cost-effective use of materials. Firing at high output also gives more efficient mixing in the burner and eradicates the production of poisonous carbon monoxide, which is caused by incomplete combustion. It also means that the burner can be accurately set at one firing rate to use the minimum amount of excess air. It is therefore advantageous to fire the burners at the highest output that can be achieved without giving rise to local high heat transfer effects in the immediate vicinity of the burners. This is the area where very careful furnace design is required [10]. Kettle wear is a function not only of the temperature to which the kettle is over-heated but the time for which that over-heating occurs. In order to understand galvanizing furnaces and select a furnace for a galvanizing plant, some of the basic heat transfer principles involved in kettle heating must be understood. Heat produced in the galvanizing furnace must be efficiently transferred to the molten zinc bath. Inefficient heating can lead to uneven heating of the kettle walls and large temperature gradients to which the steel kettle is exposed. When steel is exposed to variations in temperature, or gradients, it degrades faster than if maintained at a constant temperature. This is constantly occurring in the galvanizing kettle because portions of the kettle wall remain hotter than other sections due to the constant temperature changes in the zinc bath. In order to extend the life of the galvanizing kettle, heat must be applied as evenly as possible to the kettle walls, as well as to maintain the zinc bath as close to a constant temperature as possible.

Another way large temperature gradients can occur is when heat is not supplied to the kettle fast enough when heavy work is put through the bath. The burners must be able to supply heat to the kettle as soon as it is lost, as the result of cooler steel being dipped into the molten zinc. The temperature drop of the kettle is also dependent on the amount of zinc in the kettle. The temperature of large kettles will not drop as much as smaller kettles when the same piece of steel is dipped in each. Potential problems may arise when the galvanizing kettle is not heated uniformly. Uneven heating of the galvanizing kettle allows for degradation of the kettle walls as a direct result of hot spots formed adjacent to areas where larger amounts of heat are directed. The kettle wall requires monitoring to ensure that "hot spots" have not developed because they grow very quickly and may result in kettle failure. Once formed, these hot spots grow at an exponential rate. When kettle wall thickness is lost, heat transfers through the thinner portions at a faster rate than other sections of the wall of greater thickness. This is because these hot spots cause the thickness of the galvanizing kettle wall to decrease in only these areas. The heat has a lower thermal resistance to overcome once a hot spot is formed as a result of the thinning wall. The heat losses are decreased when hot spots develop allowing more heat to be transferred through the kettle wall, which ultimately could result in a hole. Kettle walls must be probed regularly to ensure that hot spots have not begun to develop. If kettle wall thickness is thought to be lost in areas where the flame is directed, those areas should be repaired immediately because holes in the kettle wall will develop soon thereafter. [12]

The most common fuel used to heat galvanizing kettles is natural gas. LPG is sometimes used depending on availability and price. In the past, diesel oil fired systems were used to heat conventional galvanizing kettles. Often the choice of heat source is made due to availability; whatever heat source is the cheapest and most readily available is usually chosen to heat the kettle. Electricity can also be used to heat steel galvanizing kettles. Via electrical induction, kettles are heated by coils placed in locations similar to those of gasfired kettles. Electrical heat is the perfect heating means for a galvanizing furnace because the radiant heat produced by resistance elements is very uniform, but the high cost of electricity usually precludes the use of electrical heating [12].

III. PROBLEM STATEMENT

After a few weeks of operation bulging of the kettle is found to occur at the base of the kettle wall both at the longer as well as shorter side. This may leads to the development of cracks and lead to total failure of kettle. Significant bulging at longer side is observed as compared to shorter side. It appears '*prima facie*', that bulging is due to the combination of uneven, thermal and mechanical stresses. To address the above problem, an analytical model is developed to simulate the heat transfer and fluid flow phenomena through CFD analysis.

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IV. MODELING THE GALVANIZING FURNACE

The system is modeled, meshed and exported in Fluent CFD solver. The various components of the galvanizing furnace are, Furnace or combustion zone, Burner, Exhaust duct, Kettle with floating containers of zinc and flux, and sheet to be galvanized, in the form of stationary load. The outside wall of the furnace in contact with ambient air is considered as insulated. All other walls of the kettle, at sides and bottom are considered to be conductive. Species transport model is used for combustion. The temperature distribution at the outer surface of the kettle for the given geometry and the corresponding boundary conditions, solved in Fluent 6.1 and the temperature distribution over the surface of the kettle is as shown in Fig. 3. It can be observed that the kettle surface temperature is higher at the bottom of the vertical walls of the kettle. Further, it can be stated that presence of such temperature concentration zone are significant at the bottom wall-2, as compared to wall-1.

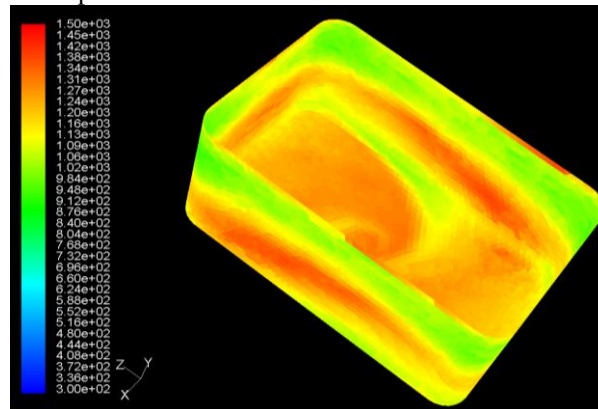


Fig. 3 Temperature over the surface of kettle

It is interesting to note that at these very places, the actual furnace wall showed the presence of mechanical stress. Mechanical stress increases continuously, traversing from top to bottom for all walls. Further possibility of buckling increases with increase in the unsupported length (traversing away from corners). Wall-2 is highly susceptible to failure under buckling stress compared to wall-1. It can be observed for the kettle wall, if considered as beam, that buckling stress will be prominent in the direction parallel to the base (in this case, the beam is subjected to the condition of ‘both end fixed’). In contrast to this, buckling stress in the direction perpendicular to the base will be less prominent (in this case the beam is subjected to the condition of ‘one end fixed and one as free’). Hence zone of high mechanical stress is at bottom of the wall-2. Fig. 3 suggests that the zone of high thermal stress is, same as earlier, at the bottom of wall-2. The kettle bulging is a metal failure, caused due to the thermally induced mechanical stresses at the bottom of the longer sides of the kettle. At the base of the kettle, one can observe that mechanical stresses are due to the hydrostatic load of molten lead, where thermal stresses are also present. However, the presence of several small square projections over which the kettle is resting, actually reduces free length and makes structure stronger against the possible failure from bottom. For the purpose of thermal stress analysis and to compare various alternatives for the solution of thermal stress included bulging, a single, unified and dimensionless number called ‘Pattern Factor’ (PF) is proposed. PF is defined as a ratio of the difference of temperature (i.e. maximum and average) over the average temperature of the zone under consideration.

$$PF = \frac{T_{max} - T_{avg}}{T_{avg}} \dots \dots (1)$$

When average temperature prevails over the entire region under consideration, the thermal stress will virtually vanish. In other words, any alternative, which results in to lower value of PF, must be preferred.

Consideration of the temperature ratio in the definition of pattern factor may be attributed to the following:

1. It is the non-uniform temperature distribution that is responsible for the generation of the buckling stress that leads to bulging.
2. The scope of problem solving strategies does not include any possibility of removing / altering / modifying mechanical stress under the present structure.

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The flue gas temperature can also be another important parameter for determining the effectiveness of the heat transfer. Since not only the uniform deployment of the heat to the walls of kettle is important, but also the maximum heat transfer to the wall is accounted in overall cost determination. Therefore uniformly distributed heat flux at a possible maximum rate ensures an effective thermal performance and efficient galvanizing process.

V. PROPOSED ALTERNATIVES

Two possible alternatives are proposed to tackle the problem of bulging of kettle:

1. Different fuel consumption rate at the burner of the furnace (for burner 1 & 3), and
2. Adopting smaller width, W between the furnace wall and kettle surface.

1. Introduction of different fuel Consumption Rate

Referring Fig. 3 it can be observed that reasons for concentrated thermal stress at the bottom of the kettle walls (wall 1 & 2) are higher heat released by the hot flue gases. Flow pattern of the flue gases suggest that the heat released by burner 1 & 3 at wall-1, reaches at the bottom of wall-2, leads to higher PF. Hence fuel reduction at the burner-1 is tried. Under this option, two reduced fuel consumptions (one with 25% & with 50% of the rated value), are studied.

From Figs. 4 & 5, it can be seen that in the case of 25% fuel reduction, concentration of thermal stress is shifted to little upward at wall-2. In case of 50% reduction, the concentration of thermal stress is shifted significantly upward. Both attempt decouples the thermal and mechanical stresses, and reduced the chances of bulging.

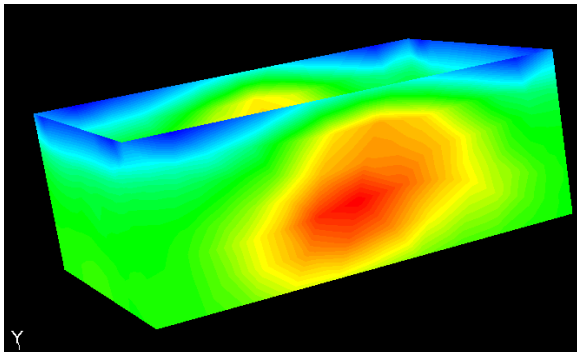


Fig. 4 25% reduction in M_f at burner-1& 3

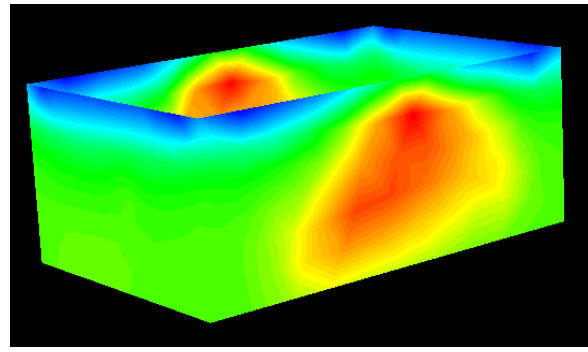


Fig. 5 50% reduction in M_f at burner-1 & 3

VI. RESULTS AND DISCUSSION

Table 1 and Fig. 7 summarize the results of the alternatives attempted with respect of PF and T_F . It is observed that with the decrease in the fuel consumption, PF scenario worsens (T_F reduces for obvious reasons). On the other hand option of reduction in the width gives lower (better) PF, and hence uniform heat transfer pattern. Amongst all options, this option provides the uniform heat availability at the inside walls of the kettle, i.e. to molten lead (refer column 1 of Table 1). However, for this option higher value of T_F , hints poor utilization of the fuel. Although, this option may be attractive for the management, since this allows management to meet its production demand (with lower down time), at the cost of little additional fuel consumption. For existing design it is observed that for all the alternatives, product of PF and T_F is almost constant. Hence out of the two alternatives (uniform and maximum heat transfer) all alternatives address only one aspect at the cost of another. Referring to the Fig. 7 it appears that any alternative will essentially follow a characteristic line, which is a hyperbolic in nature for the two given parameters, namely PF & T_F .

Above characteristic suggest constrain imposed in the existing design in terms of the location of the burners. Hence in order to generate better PF, greater control over both, number and location of the burners are essential. This suggests that in order to optimize both, uniform and maximum heat transfer, entire designs must be modified and problem of bulging should be attempted with a fresh thinking (refer Fig. 7).

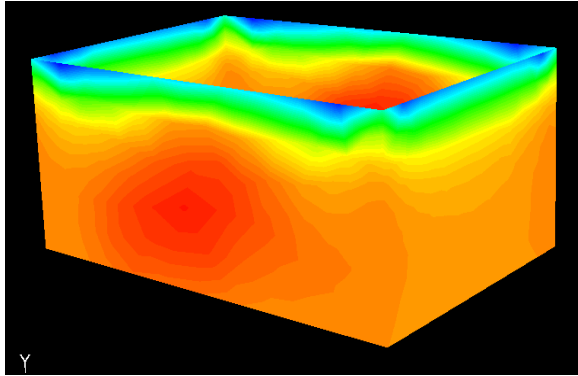


Fig. 6 Reduction in the furnace wall gap

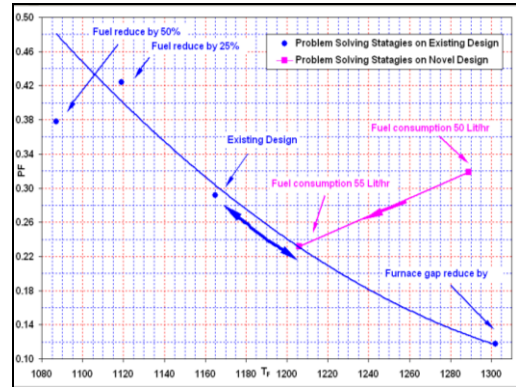


Fig.7 PF v/s T_F for various alternatives

T_{min}	T_{max}	PF	T_F
T_{max}	T_{avg}		
304	918	0.2912	1165
915	445		
Fuel ↓ by 50%			
308	976	0.3775	1087
961	441		
Fuel ↓ by 25%			
308	995	0.4239	1119
1000	435		
Width ↓ by 50%			
321	930	0.1175	1302
927	521		

Table1.PF & T_F for existing design

Novel design		
T_{max}	PF	T_F
T_{avg}		
Fuel consumption 50 lit/hr		
798.00	0.31	1289
531.00		
Fuel consumption 55 lit/hr		
862.00	0.23	1206
534.00		

Table 2.PF & T_F for Novel design

VII. NOVEL DESIGN OF GALVANIZING PROCESS

Figs. 8 & 9 illustrate the schematic of a conceptual galvanizing process. Movement of the sheet in the novel design is kept similar to that in the existing design, also the order in which sheet encounters molten lead and zinc is kept similar. For the simplicity cross section of sheet to be galvanized, kettle and furnace all are considered of circular cross sections. This also gives obvious benefit in the meshing.

To obtain better temperature distribution and control two sets of burners (with four burners in each sets offset by 45°) are provided in the design. Set-1 is exclusively for the preheating of the sheet in the lead, whereas set-2 is used to provide heat source for the molten zinc and better control over the galvanizing process.

The length of the transverse of the sheet to be galvanized is kept twice in order to reduce the fuel consumption. Further, the amount of lead required is found to decrease to 2.644 MT as compared to 11.98 MT for the present design. Further the amount of zinc is reduced to 5.6 MT instead of 21.04 MT for the existing design. Reduction in the molten lead and zinc is justified to avoid any buckling due to higher local mechanical stress.

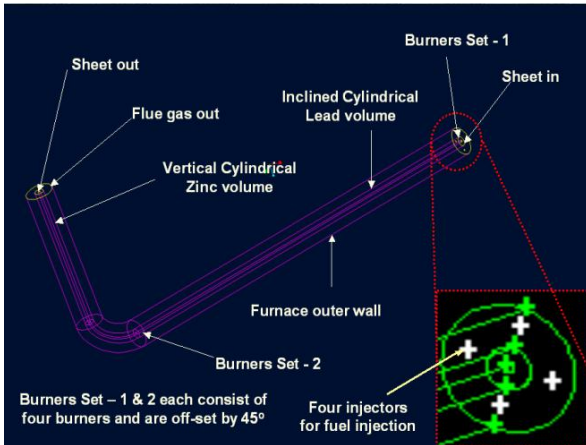


Fig. 8 Schematic of novel design

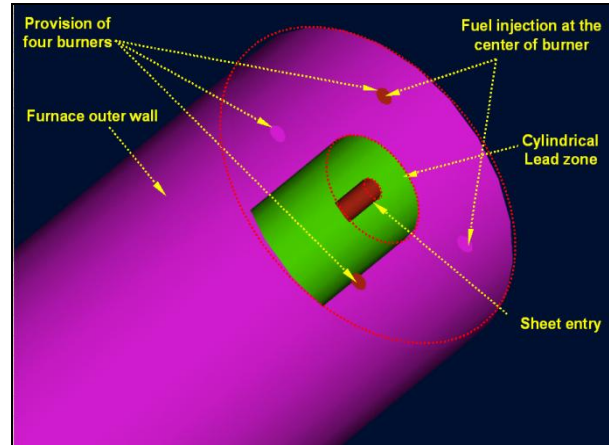


Fig. 9 Schematic of novel design

Design also provides an opportunity to reduce the heat loss to environment from the exposed molten metal. In this case exposure of molten lead to the environment is eliminated, while the same for the molten zinc is kept constant at 615 Wm^{-2} . Separate heat transfer sections for lead and zinc heating enable one to apply PF only to the zinc container. To analyze the effectiveness of this design two options are tried one with the total fuel consumption as 50 lit/hr and second with 55 lit/hr.

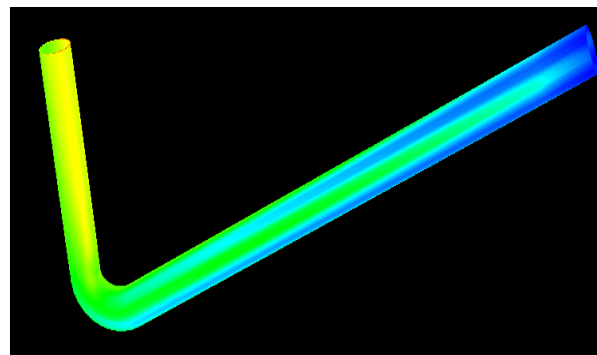


Fig. 10 Temperature distribution at the Kettle

Fig. 10 shows the temperature distribution at kettle wall containing the zinc corresponding to the fuel consumption of 50 lit/hr. insignificant uneven temperature distribution can be observed in the zone. Since the number of burners proposed is eight the design is in a better position to eliminate the uneven temperature distribution. It can also result in the lower values of PF and T_F . When the values of PF and T_F for both the options are compared with the values obtained from earlier alternatives (refer Fig.7), it is observed that increasing the fuel consumption from 50 to 55 lit/hr, both PF and T_F reduces. In this way, it is possible to achieve the objective of uniform and maximum heat transfer simultaneously.

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