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Smart Raking System Based on Computer Vision for DeSulphurisation Plant

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***Abstract*- This system has been able to standardize the raking process as a whole. This system has been able to scientifically capture the operators and engineer's skill set, experience, and expertise. Now the raking process does not remain art and dependent on few people's expertise, rather science. This invention has paved the path for conducting optimum raking for all the heats passing through desulphurization station. This has been able to generate savings in terms of yield loss of the metal. This invention has greatly improved the quality of final product. Thus the problem of over raking and under raking has been addressed. Apart from these, some intangible benefits also observed, like reduction of raking time. This has the direct effect on the productivity of the steel making. The lesser the time spent on station, means lesser heat loss to the environment. Overall, it gives the dual benefits; it reduces the energy loss and reduces the effect of process on overall environmental temperature. Additionally, this invention has been able to reduce the blame game on the operators or shifting of blames within operators for bad rakings. This has reduced the burden from the shoulders of the operators.**

I. INTRODUCTION

In an integrated steel plant, in the process chain of steel making, blast furnaces produce pig iron. This liquid hot iron is supposed to be fed to steel making shop to make the steel out of it. Unfortunately, this liquid hot metal cannot be fed directly to the LD shop as it contains many impurities. If these impurities go into the steel making process, the final product would be downgraded. Sulphur is one among these impurities, if remains in iron during steel making process, would reduce the surface finish, ductility and strength of the steel. Therefore, it need to be removed from the liquid iron before being treated in LD Vessel. Sulphur is removed from the iron in a separate treating station know as Desulphurization plant. In this plant desulphurising compounds are added to the liquid iron, which after reaction, forms sulphides. These sulphides, being lighter than iron, floats on the liquid iron as slag, as shown in Fig. 1. This slag has to be removed carefully. The process of removal of slag, by tilting the ladle (container to hold liquid iron at 1600 Degree Centigrade), by using a shovel attached to a large long boom by manual control.

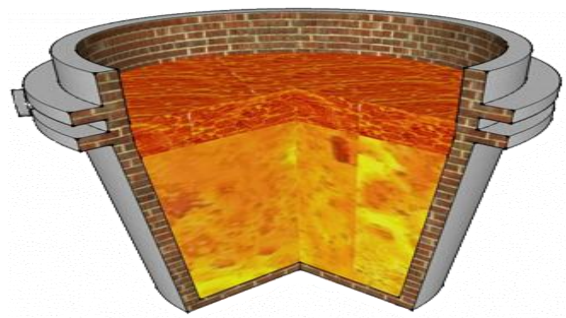

Fig 1: Slag (Sulphides) floating on treated hot metal

An operator, by using hydraulic controlled boom, skims this slag out of the surface of the liquid iron. This process of skimming out the slag from the surface of the liquid iron using booms is known as raking. An operator by his own experience and skill sets decides how much slag needs to be removed. As this process of deciding the need point is manual, chances of over-raking and under-raking always remain.

Casual operators remove very less slag from the ladle, thus causing under-raking, as shown in Fig. 2. During under-raking, a lot of slag remains in the iron, which causes detrimental effect on the steel quality. If these high Sulphur goes till the casting end, the casting speed needs to be reduced to get the slab properly without disturbing the process. Hence, this effect slows down the casting speed which causes loss of production.

Some over sincere operators make the iron ultra-clean. They tend to remove all the slag floating on the liquid iron surface (Fig. 3). This is good from the quality point of view, but in doing so, a lot of hot metal (liquid iron) also comes out with the slag. Particularly in last few hands, the composition of hot metal in the overall slag is more than 50%.

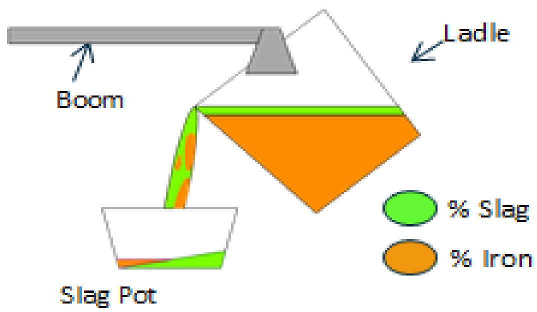

Fig 2: Casual operator causing leaving slag in ladle (under-raking)

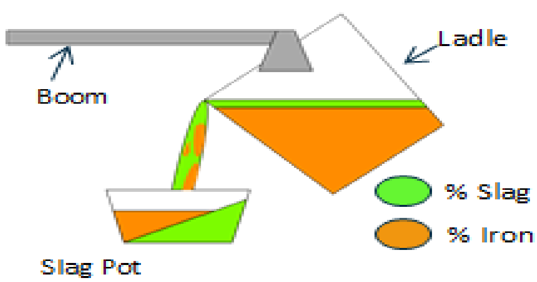

Fig 3: Over sincere operator causing liquid hot metal loss (over-raking)

Only few well-skilled, experienced operators do the raking sensibly. It is important to know that even if a particular quantity of slag is left out in the ladle, it is not going to affect the quality of steel. The smart operator uses his own discretion and judiciousness to stop the raking at a time, when a threshold amount of slag still remains in the ladle. This threshold amount is the maximum allowable slag which can go to the steel making vessel without causing detrimental effect on the steel.

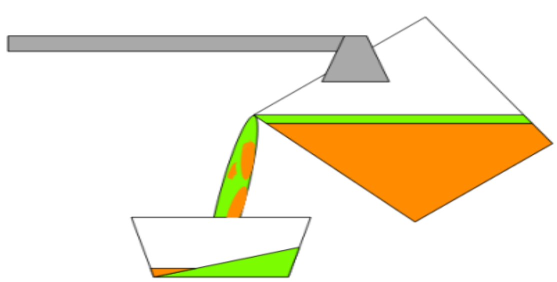

Fig 4: Smart operator causing minimum loss and removing optimum slag

However, considering the huge number of rakings going on, it is nearly impossible for a smart operator to do the optimum raking continuously day by day for 365 days, in all 3 shifts with same efficiency and repeatability.

In the light of the foregoing discussion, there was a need to develop a system which can replicate the brain and eye of the smart operator. This system should be free from human intervention, independent of the operator expertise and skill set, and should be able to provide a standardized raking process.

Comparison of the present work with past work:

Usamentiaga et al. [1], [2] developed a system for measuring the hot metal temperature when it is being tapped from the torpedo into the ladle. Generally, this is being done at the de-sulphurising area of the steel making shop. The main purpose of this process is to measure the temperature of the hot metal correctly to replace the conventional temperature measurement methods like measuring hot metal temperature using thermocouple and infrared pyrometers. On the contrary, the current work discusses about the detection of slag floating on the surface of the ladle.

Zhang et al. [3] discussed the measurement technique which includes two parts: temperature threshold calibration and region of interest determination of pouring stream (automatic tracking of the pouring stream). The tapping temperature of molten steel is required here, which could be obtained according to the sub lance of Basic oxygen Furnace. It also requires auto tracking of liquid metal stream. Within the rectangle it scans to find the column coordinate of pixel with the temperature that is greater than the threshold pre-set, and the temperature jump point is recorded. If there is no temperature jump point found until reaching the right end of the searching area, it is identified that there is no pouring stream in this frame of image.

In the current work, Raking Boom (A large long steel spoon to skim out the slag from ladle top) in and out signals were taken digitally through PLC (Programmable Logic Controller) and incorporated into the application. Thus giving the window, just between Boom out and in signals it processes the image for presence of slag. This large spoon goes in and out to remove the slag.

Chakraborty et al. [4] elaborated the software flowchart where it is grabbing the image, extracting brightness plane, thresholding the image and then calculates percentage ratio of total area of bright object inside region of interest to the entire area of region of interest and display as slag percentage (%). And then, it takes action based on threshold provided beforehand.

In the present work, temperature points are being mapped into grey scale index and with the monochrome image entire processing is done. Thus a temperature range of 300- 2000 Deg C is mapped into 0-255 grey scale values.

Process description:

The objective was to distinguish the hot metal from the slag, both seems to at the same temperature when seen through naked eye. In the visible spectrum, it is nearly impossible to use a camera and get the image to distinguish between the slag and iron. It is only in the beyond visible range, that is in the Infra-red region, the difference is evident. So a thermal camera can distinguish the difference between slag and iron based on the difference of their temperature map on the thermography cameras sensor. This difference is attributed to the difference in chemistry between slag and iron hot metal and thus the emissivity of the two are different.

A thermal camera captures the temperature points of the ladle free board. The camera provides the temperature plot of each point on the sensor, known as pixels. This temperature data is converted into intensity data. By observing the difference of temperature as pixel intensity, clear distinguishable point or threshold can be identified in the intensity scale.

So an algorithm has been devised, which tracks and maps each of the pixel's intensity. And based on the intensity value, it marks these pixels, as slag or iron. In a single frame of 3, 07,200 pixels, number of slag pixels and number of iron pixels are calculated. Based on the numbers, slag percentage or dirtiness percentage age, on the ladle board is computed.

The algorithm has a provision to compare the percentage dirtiness of a frame with that of a set point previously defined by the engineer. If the % age dirtiness crosses the previously defined dirtiness, then a provision has been made to trigger an alarm for the operator to stop raking.

It was a challenge to keep the camera in the extreme hot condition. Conventional method of cooling was not sufficient. So an innovative way of cooling has been devised. This was the first time, to the best of our knowledge; the concept of direct and indirect cooling was applied to the camera enclosure in any manufacturing plant. This actually prevented the camera temperature to go beyond 40 Deg C even during summer season.

The second big issue was dust. The dust got settled on the lens, thus preventing the optical sight of the camera. An innovative automatic shutter has been devised to keep of the dust from the lens surface. This pneumatically operated shutter automatically opens only during the raking duration. Rest of the time, it isolates the camera lens from the dust and heat of the Desulphurization process.

Apart from the shutter, a pressurized horn has also been designed, to keep of the dust during the raking duration. This prevented the dust from accumulating during raking.

An innovative data analytics method was used to generate the set point automatically thus isolating the need of the engineer to change the set point of the raking based on the grade, aim Sulphur and operational conditions.

Fig. 5: Raking process

II.SYSTEM OVERVIEW

Inception:

To overcome the limitation of employing a smart operator for each and every heat around the year, it is indeed important to have a system which can be able to replicate the abilities of the eye and brain of the smart operator.

The idea is, if it is possible to replicate successfully the ability of the smart operator, a smart raking system can be devised. The eye can be replaced with a camera whereas the brain of the operator can be replaced with an algorithm. But there were many challenges to it. Human brain, by the virtue of its learning capability which comes with experience can take decisions, which may not be possible to replicate fully using an algorithm.

Normal camera did not work, rather unable to differentiate between liquid slag and liquid hot metal. It was observed that, in visible spectrum, it is nearly impossible to find the difference between slag and hot metal. So it was thought to go beyond the visible region. The next meaningful spectrum was the Infra-red region. The reason for going to the Infrared region lies behind an assumption.

We knew slag and iron has different chemical structure. Due to their difference, it is possible for them to have different physical characteristics. The specific characteristic we were interested in was the value of emissivity. Emissivity is the measure of an object's ability to emit infrared energy. Emitted energy indicates the temperature of the object. Emissivity can have a value from 0 (shiny mirror) to 1.0 (black body).

Emissivity of an object defines at what temperature; at what wavelength the body would radiation IR energy.

Based on these principles, long wavelength IR thermography camera has been used to get the image of the free board of the ladle. The IR monitor, OEM supplied software was clearly able to show us the difference between the iron and slag. Thus a long wavelength IR camera of region 7- 14 micron, of resolution 640 x 480 was used to capture the image.

IR camera provides data in two different kinds of file structures, 8 bit and 16 bit. It is the 16 bit file, which contains the temperature/ thermal information of each and every pixel within the region of interest of the camera. These 16 bit files, rather temperature information was mapped into intensity. The grey scale intensity varies from 0 to 255, and the temperature range of the filter being used for the cameras is 600- 2000 Deg C. So a mapping was carried out for each pixel. That means for each pixel, temperature value is converted into an equivalent intensity value within a range of 0- 255. Thus a file of 16 bit can be converted into 8 bit grey scale information. This is the input for the monochrome/black and white image to be produced by the camera. This monochrome image provides sufficient information to distinguish slag from that of slag.

For the operator to get a real feel of the liquid iron, standard Iron pallet has been utilized. The monochrome image is again mapped as per the standard Iron pallet matrix. Though, the basic image processing algorithm was run on the monochrome image itself. The palletized image is being used only for the visual purpose.

Through this camera, it is possible to capture 25 frames per second. One frame consists of 640 x 480 points. For each of these many pixels a loop is being run. By trial and error methods, threshold intensity has been identified, within a range of 0-255. This defines the boundary condition within iron and slag.

Intensity of each and every pixel on a particular frame is being calculated. This pixel intensity value is compared with the threshold value/boundary condition. If the intensity of the pixel is found to be above the threshold, then that pixel would be marked as iron.

To speed up the processing, not the entire frame is analyzed. Rather only the top part, or free board part of the ladle is visualized and analyzed. This is achieved by masking the frame black, apart from the floating liquid surface.

Algorithm:

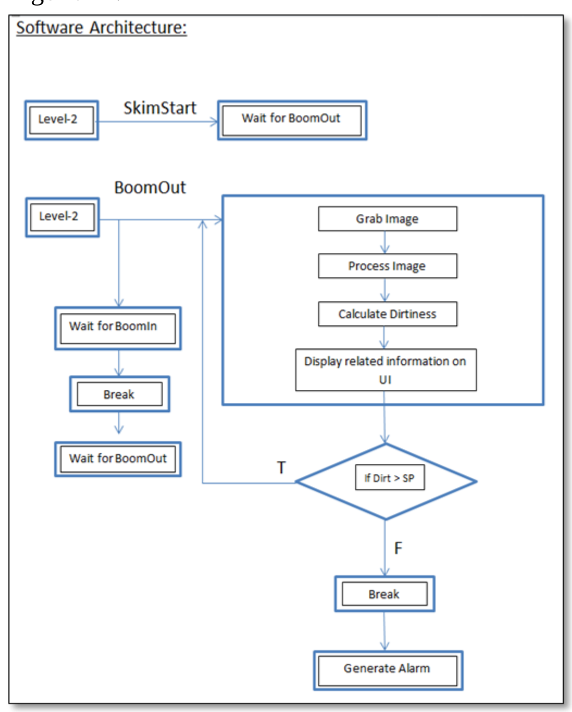

Fig. 6 Software Architecture

And if the pixel intensity is found to be below the intensity, then it would be marked as slag. For each and every frame, number of slag and iron pixels is being calculated. The percentage of slag pixels are calculated from out of the whole number of pixels. This gives the percentage dirtiness on the ladle free board. Again, based on various iterations of trials and errors, a threshold percentage of dirtiness has been found. This value corresponds to the maximum allowable slag, which can be left in ladle, and is not going to create any detrimental effect on the quality of the final product, that is steel.

Now to get rid of fluctuations, a moving median value of percentage dirtiness is calculated. This is calculated on a window size of 10. This is done by taking dirtiness values of ten consecutive frames and storing them in an array. Now the median of these ten values are calculated. This median value would be considered the value of dirtiness of the tenth frame. This helped us to tackle the frequent problem of fumes and fluctuation due to disturbed liquid surface due to boom movement. Now this percentage value would be compared each and every time with that of the threshold value /set point. If a particular frame crosses this value, immediately alarm is not generated to stop raking. As due to boom movement, instantaneous cleaning of surface occurs but immediately after, the free board is again covered with slag. To get rid of these phenomena, a special filter is designed. Now the number of consecutive times the frames crosses the set point, it would be stored in an array. When this value reaches 7, then the stop alarm signal is being generated. This signal is latched to Level-2 network, through which it is passed on to PLC, which triggers a Digital signal to fire an Alarm for the operator to stop raking process. The algorithm flowchart is shown in Fig. 6.

Engineering:

During installation, major problem was faced during meaningful data capturing. As the large boom is going in and out of the ladle surface, it was very difficult to get the unhindered view of the ladle free board. An innovative way was found out. An encoder was fixed on the boom which provides the linear movement of the boom (Fig. 7). This is interfaced with the PLC. In PLC, a program has been written to generate two digital signals. When the tip of the boom comes out of the ladle lip, an out signal is generated. At the same time, when the boom approaches to enter the lip of the ladle, IN digital signal has been generated. These two signals are tapped into the Level-2 server, and through telegram been transferred to the smart raking server. The processing or image acquisition happens only within the duration between IN and out signals. This occurs for 3-4 seconds when no boom could be seen inside the ladle free board. Within this time only images are being captured for processing.

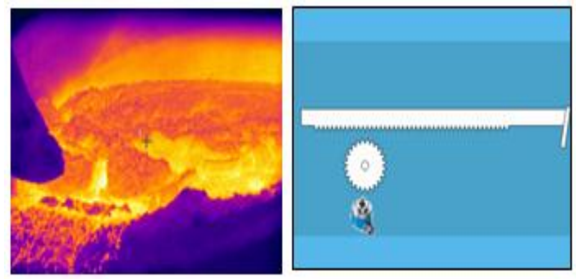

Fig 7: Boom in/out signal generation

Temperature was the next big hurdle in installing this system. To get a proper view of the ladle free board, the camera needs to be put very close to the protection wall. The ladle is carrying hot metal of temperature 1600 degree centigrade. The camera location was hardly five meters away from the ladle. Thus it becomes very important to keep the camera safe from extreme high temperature round the year, across all the seasons.

The conventional camera enclosure has one vortex cooler which is being put within the double wall of the cylinder. Using a self-made data logger, we tried to capture the temperature of the enclosure for the whole day, and found that the temperature is going above 60 Degree C with one vortex cooler fitted externally as designed by the supplier. Chilled water cannot be used as it poses safety concerns, considering the area has carbide scattered all along. It was found that one vortex cooler can bring down the temperature by 20-30 Degree from the environment. So by using basic arithmetic, we thought the temperature can be brought down by 40 Degree Centigrade using two vortex coolers. Based on this thinking, a separate vortex cooler was introduced and the cold air is pushed inside the camera enclosure to cool the camera directly. Thus two types of cooling are being used, direct and indirect. Using these two kinds of vortex coolers, again the data logger has been kept within the enclosure for one day, and the result was surprising, rather as per our expectation. We found the temperature of the enclosure has come down to 40 Degree and a drop of 30 Degree from the environment. This innovative and novel approach in cooling allowed the camera to be installed in close vicinity to that of the hot ladle. The cooling system is shown in Fig 8.

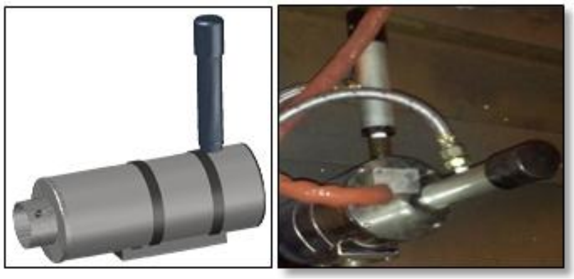

Fig 8: Original as well as modified cooling system

The next big problem was dust. Desulphurising area generates a lot of dust. This dust consists of sulphides, carbides and lime, which is very sticky in nature. During the injection process, a vigorous reaction takes place within the ladle. During this process lot of dust and fumes are being generated. Even in the presence of dust catchers and suctions tubes, a lot of dust and fume come out of the slot and gets deposited on the enclosure window. After prolonged exposure, the enclosure becomes almost opaque for the IR radiation to pass through. To overcome this problem, an automatic shutter arrangement has been through of. A pneumatic cylinder is used, whose arm is fitted with a stain less steel plate. The pneumatic cylinder is being operated automatically through the PLC (Programmable logic controller) generated signal on raking start and finish. As soon as the raking start signal generated, the shutter opens the slot cut on the wall and as soon as it receives the finish signal, it closes the slot. This arrangement has saved a lot of fumes generated during injection time, to get deposited on the window. By this arrangement, 70% of dust problem has been sorted out.

But dust problem still remains. During raking process also, a lot of dust and fume is generated and sticks on the window. Though the frequency of cleaning to get unhindered view has reduced but still the problem remained. Now this time a pressurized horn arrangement has been designed (Fig 9). This horn is a pipe like structure with a nozzle to connect air/nitrogen line. When pressurized air or nitrogen is connected to the nozzle, a positive pressure chamber is being created just in front of the enclosure window. This pressurized chamber doesn't allow the dust to pass through and get deposited on the window. Apart from this, an air knife has also been used which is doing its part to prevent dust to get in contact with the enclosure window. By applying these modifications, ultimately the system has overcome all the problems.

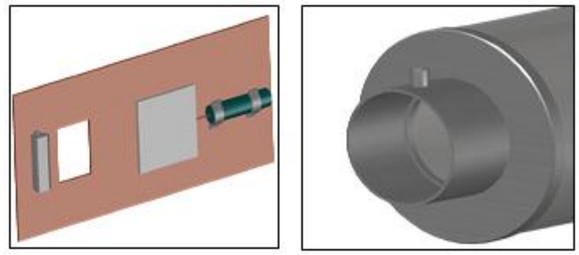

Fig 9: Shutter and horn arrangement

III. BASIC THEORY AND ALGORTHM

a) Infrared Temperature Measurement Theory:

Infrared thermograph is a thermal interpretation of thermal radiation from the object or simply we can say "writing with heat".

An infrared thermometer measures temperature by detecting the infrared energy emitted by all materials which are at temperatures above absolute zero, (0 Degree Kelvin) [5]. The basic design is to concentrate the infrared radiation to the detector using a lens, which is then converted into proportional electrical signal. This can be used in units of temperature after atmospheric temperature compensation. This configuration facilitates temperature measurement from a distance without contact with the object to be measured. Direct measurement is not always suitable or possible for temperature measurement of various applications for different reasons. Most thermocouples cannot be used if the object of interest is non static, or behind an electromagnetic wave field as it happens in induction heating or an application where higher response time is required.

b) Principle of Measurement:

Infrared (IR) radiation radiated by objects of temperature above 0 Degree K is part of EM spectrum. Its wavelength lies beyond visible and up to radio waves.

The IR radiation starts from 0.7 micrometers to 1000 micrometers. For everyday temperature measurement, only the wavelengths of 0.7 microns to 20 microns are used. Present technology cannot detect or is not sensitive enough to pick up small amount of energy after 20 microns [6], [7], [8] , [9], [10], [11].

All the materials or compounds have different chemical structure thus different emissivity. So they emit different intensity of IR radiation at same temperature. Colour of a substance cannot dictate the emissivity function unless its substance is radically different from base material.

c) Infrared Radiation Temperature Measurement Theory:

7-14 microns is a selective range where the measurement hardly gets affected by atmospheric disturbances like moisture dust etc. Thin film plastic can be measured with 7.9 microns whereas 3.86 microns is best suited for avoidance against the CO_2 and H_2O vapor in case of flames and combustible gases.

The choice of longer vs shorter wavelength is governed by temperature range of objects.

Applications, which do not demand selective filtering for the above stated reasons may often benefit from a narrow spectral response as close to 0.7 microns as possible. Materials exhibit highest effective emissivity at shorter wavelengths and if we use IR camera that has spectral response limited to small region on the wavelength scale, it is likely to be invariant of small turbulences caused by change in external factors.

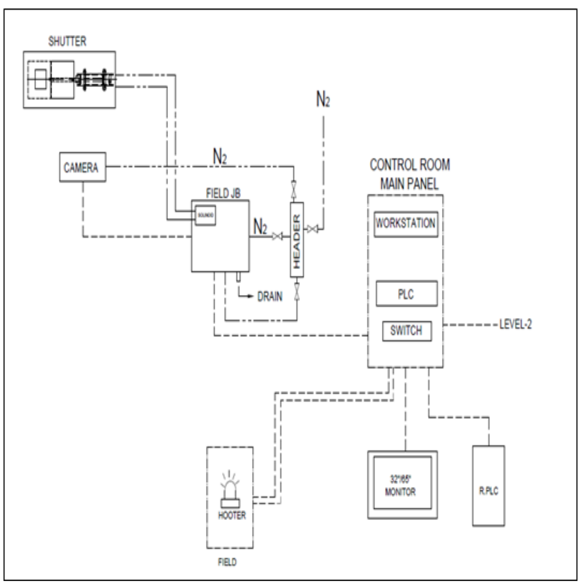

Fig. 10: Arrangement of Smart Raking System

The following picture shows the screen shot of a live system running in one of the steel making shops.

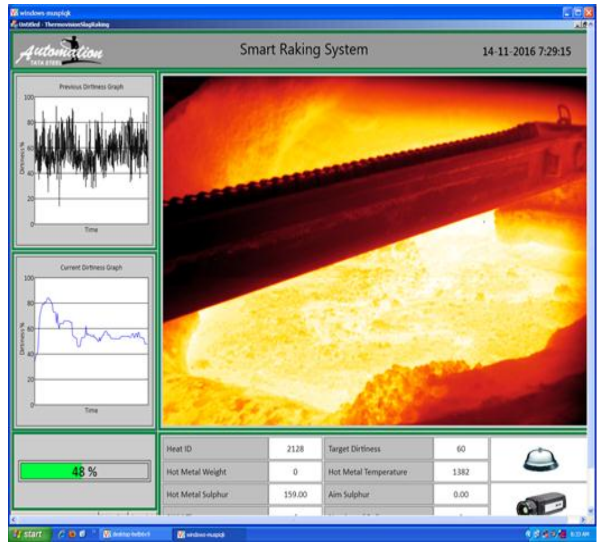

Fig. 11: Picture of the Raking while skimming is going on

Fig. 12 : Onsite installation of the camera unit along with nitrogen cooling facilities.

IV.RESULTS

By implementing this system direct impact on bottom line can be observed. We have classified this in tangible and non-tangible benefits.

Tangible:

- Hot metal yield improved(2.9 to 1.8 T /batch)
- 36% decrease in metal loss
- 27 % Reduction in speed loss in casting due to high ‘Sulphur’
- Non tangible:
- Raking process standardised
- Independent of human skill and experience
- Raking time decreased, productivity increased
- Operator stress level decreased as he need not take the call to stop tapping anymore.

V. CONCLUSION

Smart Raking system provides the following benefits to the plant:

- Automatic detection of raking end point.
- Eliminates manual intervention by application of computer vision architecture to decision-making
- Increases yield, quality and productivity

After implementation, this system has been able to generate savings from the iron yield loss. This has able to improve quality, productivity and raking time, and reduced heat loss to the environment. For the first time in India, a smart and intelligent raking system has been designed, developed and implemented. The novelty lies in the use of Artificial Intelligence and Image Processing techniques to separate the slag and steel.

The loss of iron in the slag has come down. However, the major benefit has been the quality of the high strength steel grades for the automotive sector. The raking system has been engineered indigenously.

The system can be deployed in other steel making shops existing in India and abroad. The concept can also be used in industries beyond Steel making e.g. Aluminum, Copper and Zinc. In the long term, the raking system could be upgraded to an automated raking installation.

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