Economical and Technical Way of Ladle Pre-heating by the Use of Flameless Oxyfuel (HSD/LPG) Gas in the Steel Industry

Mohammad S Alsoufi
Umm Al-Qura University

Mohammed Yunus
Umm Al-Qura University,saudi arabia, mecca.

Mohammed Asadulla
Nalla Malla Reddy Engineering college

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Economical and Technical Way of Ladle Pre-heating by the Use of Flameless Oxyfuel (HSD/LPG) Gas in the Steel Industry

Dr. Mohammad S. Alsoufi[1], Dr. Mohammed Yunus[1] and Mr. Mohammed Asadullah[2]

[1]Mechanical Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makkah, KSA.

[2]Mechanical Engineering Department, NRI Institute of Technology, Hyderabad, India.

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ABSTRACT

For efficient heating with lesser fuel consumption and a quick way of heating, oxyfuel has been clearly shown to produce very low emissions of CO_2 and NO_X as compared to air-fuel for fifteen years. Among oxyfuels, flameless oxyfuels can be even more economical and technically superior for higher production rates, excellent uniform heating and very low NO_X emissions. In the present study, our casting centres have accommodated a number of reheating furnaces along with preheating stands working on flameless oxyfuel to one tonne capacity of smallest size ladles. Flameless oxyfuel has improved to a greater uniformity in heat distribution and decreased fuel consumption approximately by 30-65% compared to air-fuel mixture. It also falls to low NO_X emission during high levels of ingress air, which is essential for economical use. In this work it lowered scaling losses, refractory wear during reheating and ladle preheating respectively by improving the steel quality to be produced during casting. It is also seen that for low calorific value (below 7-7.5 MJ/Nm^3) gases such as top gas released from the furnace, use of oxyfuel combustion is an absolute requirement. With the advances in today's technology, combining air-fuel and flameless oxyfuel can create semi-flameless combustion without replacing the air-fuel burners. The paper highlights the working of flameless oxyfuel and its application and also presents the results that have been achieved in controlling pollution and consumption.

1.Introduction

Oxyfuel has taken over the air fuel method of heating in terms of reheating and annealing of furnaces, vessels and so on due to its improved thermal efficiency, the heating rate, uniformity of temperature and increased productivity and also that less amount of fuel is required to heat the product to the desired temperature with minimal CO_2 and NO_X emissions. Now flameless oxyfuel, increase in throughput capacity, fuel saving and reduction of emission of CO_2 are up to 50% along with the reduction of NO_X emissions and scaling losses. In heating, if all the reheating and annealing furnaces would employ oxyfuel combustion, the CO_2 emissions from the world steel industries would be reduced by over 100 million tons per annum. Particularly in vessel preheating using flameless oxyfuel, great benefits are shown. An excellent economic outcome has been obtained from ladle and converter preheating using flameless oxyfuel by converting furnaces and vessel preheating stands into all oxyfuel operating showing energy savings from 25% to 75%, excluding the savings in energy needed to bring natural gas from its sources to the combustion point. During usage of oxyfuel, the systems increased the oxygen content of the combustion air with encouraging results of reduced fuel consumption and increased output (tons per hour) [1].

1.1. Ladle

In a foundry, a ladle is a vessel used to transport and pour out molten metal (as shown in Figure 1). Ladles differ in size ranging from hand carried vessels which resemble a kitchen ladle and have a carrying size of up to 20 kilograms or to large size steel mill ladles that can carry up to 300 tons (330 tons). Most of the non-ferrous foundries also use ceramic crucibles for transporting and pouring molten metal and will also refer to these as ladles. The basic design can therefore include many variations that improve the usability of the ladle for specific tasks, e.g., [2]:

- **Casting Ladle:** This type of ladle is used for pouring molten metal into moulds meant for producing casting/cast products.
- **Transfer Ladle:** Moving a large amount of molten metal from one process to another is carried out by this type of ladle or from a primary stage melting furnace to a holding furnace or auto-pour unit center.
- **Treatment Ladle:** For changing some aspects or treating molten metal to turn it into alloys and to take place within the ladle, e.g., converting cast iron to steel by the addition of various elements into the ladle.

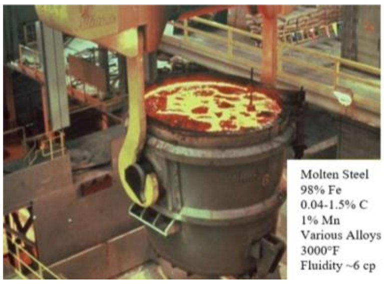

Figure 1. ladle containing molten steel, adapted from [2].

Tele:
E-mail address: yunus.mohammed@rediffmail.com

1.2. Pour Designs

Ladles are classified into "*lip pour*" design, "*teapot spout*" design, "*lip-axis*" design or "*bottom pour*" design [3]:

- The "lip pour" design ladle is tilted, and molten metal flows out of the ladle like water from the pitcher.
- The "teapot spout" design ladle resembles a teapot, takes a liquid from the base of a ladle and pours it out through a lip-pour spout. Any of the impurities present in the molten metal will form on the top of the metal so by taking the metal from the base of the ladle, the impurities are not poured into the mould. The same idea is behind the bottom pour process.
- The "lip-axis" design ladle has the pivot point of the vessel as close to the tip of the pouring spout as is practicable and thus when the ladle is rotated the actual pouring point has very little movement. Lip-axis pouring is often used on molten metal pouring systems where there is a need to automate the process as much as possible and the operator controls the pouring operation at a remote distance.
- The "bottom pour" design ladle in which a stopper rod is inserted into a tapping hole in the bottom of the ladle. To pour metal the stopper is raised vertically to allow the metal to flow out the bottom of the ladle. To stop pouring the stopper rod is inserted back into the drain hole. Large ladles in the steelmaking industry may use slide gates below the taphole.

2. Ladle Pre-heating

Due to the importance of drying a new ladle lining to avoid an explosion after adding molten metal observed by operators from past few years in both steel production plants and foundries, the drying or heating operation of ladles has become a necessary process. Ensuring preheating of the ladle lining is both important to the process as well as ensuring the product does not cool excessively and also increases the life of the lining materials. The range of ladle preheating systems operating up to 1300°C. These systems can be manual, or power slew, and all come with local burner control and temperature detector [4]. From few years, in steel and foundry plants, operators started recognizing the importance of drying ladle refractory lining to avoid an explosion at the time of adding molten metal. Thus, the drying or heating operation of ladles is often called ladle preheating. These ladles need preheating, so that thermal shock and damage to the refractory lining and temperature drop in the ladle are minimized. These inventions relate to steelmaking and more particularly to a method of preheating steelmaking ladles. The ladles size may be as large as enough to hold molten steel from 30 to 200 tons or more. To carry out continuous steel production, several ladles need to be rotated through the melt shop and casting shop simultaneously. Thermal state of the ladles plays an important role on the length of the operation in producing steel. The refractories lining of the ladle is continuously be heated to the same temperature (1482 °C to 1593°C) equal to molten steel. The ladles sometimes recycled through the melt and casting shops will cool as the molten steel is discharged into the caster, and cool further before the ladle is returned for recharging in the melt shop. Moreover, if ladles are taken offline in the steel production cycle after cooling down to room temperature, and the replacement ladles have to be heated from ambient temperature to operating temperature. Furthermore, ladles required to be preheated for reducing the length of the operation, facilities and increasing melt shop capacity during steel making [5].

In other words, ladles need to be heated up after pouring molten metal as heat will be absorbed by the refractory lining from the melt. That means the ladles will be cool down when emptied and the duration of a ladle remaining empty is variable and unpredictable at times. Sometimes due to major delays like repairing hours ladle remains cold. Under this cold condition, the duration of steelmaking operation will be considerably increased as ladles be heated with the molten metal to steel producing temperature.

Usually preheating of ladles has been performed with a gas-fired burner which injected a combustion flame into the interior of the ladle to the desired temperature between 982 °C and 1093°C. The temperature of the ladle during the preheating process may be measured and controlled using a thermocouple or pyrometer. Due to this, damage to the refractories from overheating by a conventional method of ladle preheating. They also have involved consumption of large quantity of fuel, such as natural gas, and have resulted in [6].

Accordingly, there could be many methods to reduce the fuel consumption during preheating of the ladle refractories for use in steelmaking to the desired temperature efficiently while inhibiting damage and wear of the refractories from overheating [7]. Figure 2 is a schematic drawing showing a ladle and a preheater for use in a method of preheating steelmaking ladles [7, 8].

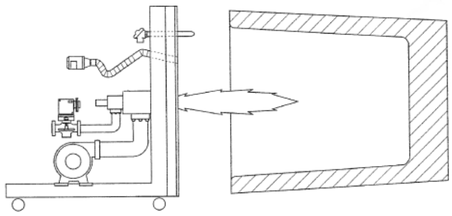

Figure 2: ladle and a pre-heater for method of pre-heating steelmaking ladles, adapted from [7, 8]

2.1. Ladle Pre-heater

A ladle preheater is used for removing the moisture from the ladle to prevent the gas formation or reaction with the liquid metal. It could be designed for both vertical and horizontal type depending on the strength, capacity and size of the ladle. A vertical ladle preheater is one which is designed to have fired from the top to downwards. The preheater will be on an axle so that cowl can rotate up to 360°. The cowl will be lined with refractory to increase the flue travelling time, whereas a horizontal one is designed to fire horizontally. The ladle will be positioned opposite the flame direction with a minimum gap between the burner and the burner firing which will be focused on the side walls of the ladle. In ladle preheaters, the flame will be positioned in such a way as to slide on the ladle side wall to ensure faster heat penetration. A properly designed ladle preheater gives a far more efficient and controlled method of pre-heating a ladle than the traditional methods of using a gas flame. The energy consumption of these systems is notoriously poor and, in some cases, heating a cold ladle using these methods can lead to efficiencies of less than 10%. They can also lead to uneven distribution of heat so that the ladle has both hot and cold spots leading to premature lining failure and variable metal quality. Therefore, a ladle preheater can be economical, more fuel efficient, reduces damages to the refractory lining by proper design. It also minimizes the reduction of the temperature loss of the metal while it is in the refractory lining damage due to a poorly dried lining still having a significant moisture content and ensuring that the ladle is evenly pre-heated [9].

2.2. Necessity to Pre-heat the Ladle

The following procedure are followed [10]:

- Preventing explosions resulting from the sudden conversion of moisture entrapped in the ladle refractory to steam when molten metal is added.
- Removal of metal solidification in the ladle head which requires maintenance time, labor to remove and can affect the metal quality and pouring from the ladle.
- Decreasing pouring temperatures to save metal heating costs.
- Reducing thermal shock to the ladle lining to increase the lining life.
- Enhancing the life of lining from controlled temperatures during drying of new linings.
- Decreasing the losses of heat from molten metal during a continuous casting operation.
- Rapid temperature losses can result in metal freezing in the ladle and tundish nozzles.

2.3. Method of Pre-heating Steelmaking Ladles

A method for preheating a ladle used in steel production to reduce fuel consumption in heating and achieving accurate temperature control. The preheating process temperature can be monitored by a burner unit based on pyrometer measurements of refractories. The heating unit includes an emissive coating to prevent heat loss, and a valve mechanism to vary the flame size of the burner accurately during an idle stage of the preheating process. A preheating method in a steelmaking ladle having an open upper portion and inner refractory surfaces comprises the following steps [11]:

a) Placing a preheater having a radiant reflective surface and at least one burner adjacent to open upper portion of the steel producing ladle comprising an emissive coating.

b) Heating the inner refractory surfaces of the steel producing ladle to the desired temperature by combustion through the preheater burner.

c) Placing a pyrometer to measure current temperature of the inner refractory surfaces of the steel producing ladle at the time of heating.

d) Electrical signals generated should indicate the current temperature of the inner refractory surfaces of the steel producing measured by the pyrometer.

e) Controlling the preheater temperature at the inner refractory surfaces of the steel producing ladle using the generated electrical signals by the pyrometer.

The method of preheating a steelmaking ladle is done where the inner refractory surfaces of the steelmaking ladle are heated to a temperature between 982°C and 1149°C [4].

In this method, open upper portion of the steel producing ladle is positioned substantially opposite the radiant reflective surface with an emissive coating of the pre-heater. A gap of no more than 3 to 8 inches is maintained between the radiant reflective surface of the pre-heater and the open upper portion of the steelmaking ladle where the emissive coating is a silicide coating which is selected from the group consisting of molybdenum silicide, tantalum silicide, niobium silicide and a combination thereof. An emissive coating has an emissivity between 0.85 and 0.95. The radiant reflective surface with the emissive coating is disposed on a refractory surface of the pre-heater. It consists of a burner heating unit, the method comprising of an additional step of regulating a fuel flow rate, air and oxygen to the burner during an idle state of the burner between preheating cycles is set to not higher than 600 SCFH during the idle state and temperature readings obtained from a pyrometer. It comprises of positioning the heating unit adjacent to an open upper portion of the steelmaking ladle, wherein the heating unit comprises a radiant reflective surface having an emissive coating which is disposed on a refractory surface of the heating unit. It also includes heating inner refractory surfaces of the steelmaking ladle to the desired temperature by combustion through the burner of the heating unit where the radiant reflective surface facilitates preheating of the steelmaking ladle [12]. The positioning of a pyrometer of the pre-heater is needed to measure current temperature of an inner refractory surface of the steel producing ladle during preheating and to control the temperature of the preheating by the pre-heater. [1].

3. Ladle Pre-heating Process

The following procedure were followed as mentioned in [13]:

- Keep the new ladle on the ladle preheat stand as near to the burner as possible.
- Start the first heating to remove any moisture in the lining by keeping the flame low (duration 2-3 hrs.).
- Turn off the burner and start the second preheating with a full flame touching up to the ladle bottom.
- Wait until the inside of the ladle becomes dull red in color (approx. temp 1200°C).
- Lift the ladle when required.

3.1. Ladle Pre-heating Cycle

Figure 4 illustrates the ladle pre-heating cycle. The following steps were followed:

- Raising temperature room into 300°C in 3 hours at 100°C/hr.
- Soaking at 300°C for 3 hours.
- Raising temperature from 300°C to 1200°C in 9 hours at 100°C/hr.
- Soaking at 1200°C for 5 hours.
- If preheating is prolonged, lowering temperature from 1200 to 1000°C in 2 hrs.
- Soaking at 1000°C for prescribed time.

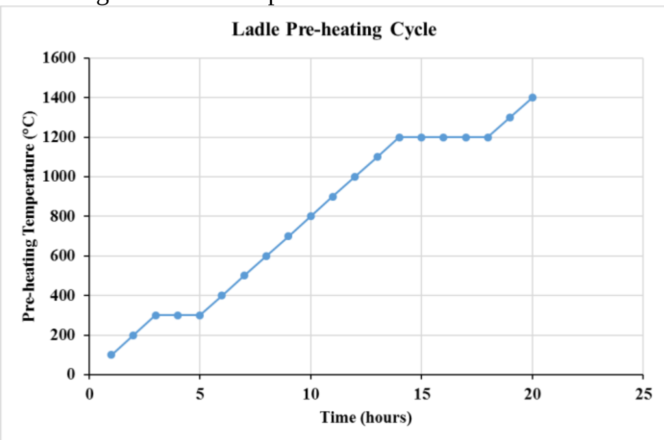

Figure 4. ladle pre-heating cycle.

3.2. Conceptual System

A ladle preheating station consists of a single firing hood fitted with one burner. The hood is mounted onto a trolley is driven by 0.5HP geared motor for cross movement. Limit switches and mechanical stoppers on both directions restrict this cross movement. The hood with the cross trolley is mounted on the main trolley, which is capable of moving longitudinally on a rail track with an Electro Mechanical through geared motor or the movement. The ladle is positioned in front of the ladle firing hood on a suitable ladle stand.

Once the ladle is placed on the firing hood is to be moved right in front of the ladle (as close as possible) by moving both the main and firing hood trolley. The burner of the firing hood is positioned at the center. The burner is provided with automatically controlled butterfly valves for combustion and atomizing air. The burner is also provided with an oil control sensatory valve. The centrifugal steel plate air blower of capacity 700 CFM at 40 WG driven by 10 HP motor, directly driven is provided. The blower is placed on the main trolley. The airline connecting the burner from the blower is provided with a motorized butterfly valve. The end connection is of flexible type hose to facilitate cross trolley movement. A duplex pumping filtering and pressure control composite unit are provided near the main trolley and a ring main pipe line at a convenient level for flexible connection. The firing hood is provided with a motorized oil control valve near the burner. This oil line also has an oil shut off solenoid valve. The connection between the rings main on these control pipelines is through a quick release braided flexible hose [14].

The firing hood is provided with a thermocouple for sensing the temperature during heating and the signal is fed into an on/off type digital PID controller provided on a separate control panel to set the desired ladle preheating temperature. The controller which actuates the motorized butterfly valve on the combustion air line and oil line which facilitates high/low firing inside the ladle for controlled heating of the ladle [3]. The burner is provided with a pilot burner with an igniter, a UV flame sensor and a flame monitor to ensure the oil throughput to the burner is cut off in case of flame failure [3, 14].

A heating device for preheating a container, such as a ladle transfer, transferring liquid metal, ladle surface is lined with refractory material, wherein the container is heated in a heating stand having a container closure lid, is characterized by the use of porous burners for heating the container and keeping it warm. The vessel is heated in a heating stand that has a vessel cover, for heating and maintaining the vessel temperature. Therefore, the porous burners are constructed and arranged in the form of arrays. [14].

4. Flameless Oxyfuel

In recent times, flameless oxy fuel combustion has been employed with the aim of communicating the visual aspect of the combustion type (either the flame is no longer seen or is easily detected) or that combustion is extended in time and space such as in volume combustion. Such a flame exhibits a uniform and lowers the temperature with the same amount of energy as shown in Figure 5. The uniform reaction of mixture of fuel and oxidant through the flame volume at a rate partial pressures of reactants and their temperature. Flameless oxy fuel burners efficiently disperse the combustion gases throughout the furnace to ensure more efficient and allows uniform heating of the material with a limited number of burners installed. NOx formation reduces as the flame temperature lowered substantially is important from a global warming point of view because global warming will be reduced equivalent to 300 times that of CO_2. Figure 6 shows the increase in the efficiency using flameless oxy fuel. [15].

Oxy-fuel burners have always been powerful, and compact to facilitate an exchange of existing burners and retrofit of new burners. Moreover, flameless oxy-fuel combustion adds advantages of opening up of new applications with a substantially decreased impact of the environment.

This reduces the flame temperature to prevent the formation of thermal NO_X and maintains homogenous heating. The picture (refer figure 5) depicted flameless oxy-fuel combustion with a diluted and changed into transparent flame.

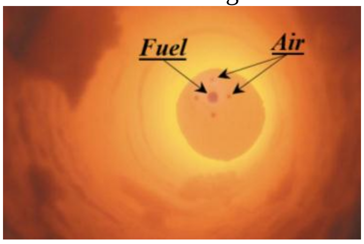

Figure 5. uniform volume combustion and low temperature flame, adapted from [15].

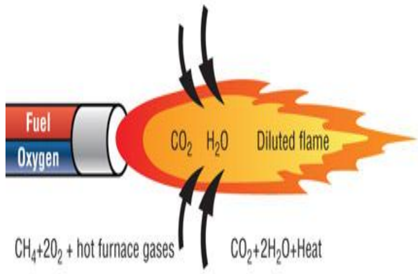

Figure 6. flameless oxyfuel combustion diluted by the hot furnace gases, adapted from [15].

4.1. Advantages of using Flameless Oxyfuel in Ladle Pre-heating

- Surface quality will be improved.
- Temperature uniformity of the slabs is easily achieved.
- Ideal heating curve suggested by the control system can be achieved more easily.
- Improves the plant environment greatly by reducing smoke emitting from the furnace.
- It reduces NO_X emission by 45%.
- Reductions in SO_2 and CO_2 emissions. Therefore, decreases fuel consumption by 25%.
- Increases overall Production process by 15-20%. No negative impact on the surface quality.

4.2. Types of Flameless Oxyfuel

There are two types of flameless oxyfuel used, namely Diesel Fuels (HSD/LDO) and LPG (Liquefied Petroleum Gas). Industries require cost-effective and efficient energy solutions for their various processes. In most applications, LPG is used as a clean and cost-effective fuel in furnaces, kilns, ovens, dryers, boilers, thermic fluid heaters, hot air generators and so on. Besides, providing numerous other benefits. LPG's energy density (calorific value per unit mass) is higher than conventional fuels, and there are no residues and unburnt products of combustion, making it a compact and energy-efficient fuel. LPG is cost-effective compared to electricity, Diesel (HSD/LDO) and Petrol. It gives you savings in fuel bills as well as other associated costs. It provides superior product quality as the temperature can be controlled easily and accurately. It is clean and environmentally-friendly. LPG gives a clean blue flame. Because it does not produce harmful emissions such as soot, smoke, unburnt carbon particles. LPG is easy to operate, much simpler to maintain owing to the availability of fewer accessories. Neither it requires frequent cleaning, nor it gives instant heat. Hence, the desired temperature is reached in quick time increasing productivity. Neither LPG nor its products of combustion contaminate the product ensuring that the product is hygienic and of superior quality [6].

5. Results and Discussions

5.1. Economic Analysis

Graphs 7, 8 and 9 shows the variation of the amount of fuel HSD/LPG consumed by each ladle in pre-heating during a course period of 8 months in pre-heating ladles. As seen in the graph it is found that consumption of HSD to pre-heat ladle is more than that of LPG. Using LPG is economical as consumption of it and pollutants after combustion are lesser than that of HSD [16]. But, it is also evident that HSD is used more frequently than LPG in pre-heating of ladles. It is found that though the consumption of LPG per ladle is less than HSD the cost factor comes on top. It is seen that the cost of HSD is much lower than Industrial LPG and HSD is more freely available in the necessary quantities. Also storage of LPG is very difficult because of its high pressure. It requires high pressure containers to store gas which increases its storage requirements whereas HSD can be stored normally [17].

Taking into account all aspects HSD is superior to LPG. Also, pre-heating of ladles is faster using LPG as the flame is instant and does not require any external aid to increase flame propagation. Ladle pre-heaters using LPG are simple in construction as no aid is required to increase the velocity of the flame as in pre-heaters that use HSD as fuel. Pre-heating of ladles using HSD requires external high pressure for flame propagation. Extra blowers are attached to the system to increase the pressure of inlet HSD for pre-heating of ladles. The flame so produced is not instant and pre-heating of ladles is slower than that of ladle pre-heaters using LPG.

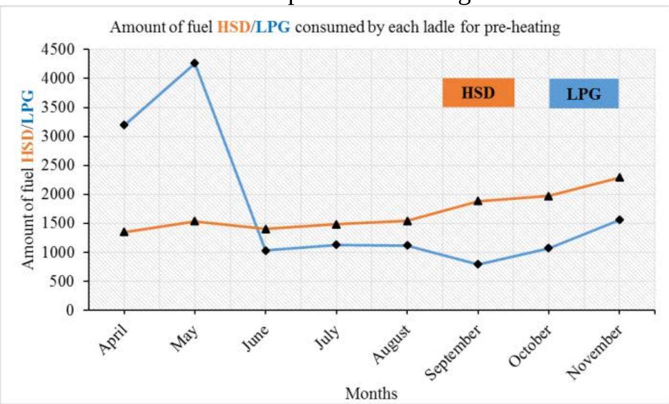

Figure 7. amount of fuel HSD/LPG consumed by each ladle for pre-heating during 8 months.

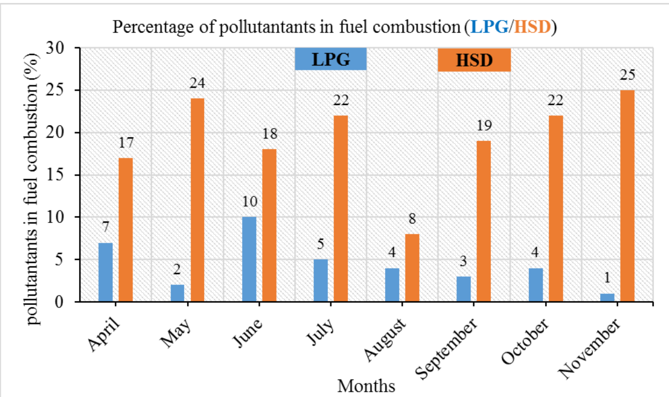

Figure 8. percentage of pollutantants in fuel combustion.

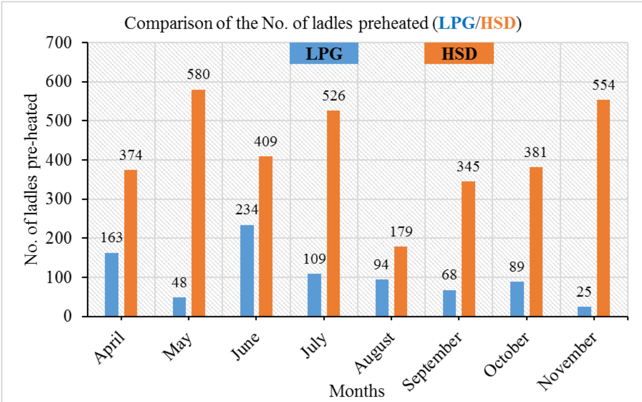

Figure 9. comparison of number of ladles preheated.

5.2. Energy Efficiency

To determine energy efficiency, in an air-fuel burner the burner flame contains nitrogen from the combustion air. A significant amount of the fuel energy is used to heat up this nitrogen. The hot nitrogen leaves through the stack, creating energy losses. When avoiding the nitrogen ballast, by the use of industrial grade oxygen, then not only is the combustion itself more efficient but also the heat transfer. Oxyfuel combustion influences the combustion process in many ways. The first obvious result is the increase in thermal efficiency due to the reduced exhaust gas volume, a result that is fundamental and valid for all types of oxyfuel burners. Additionally, the concentration of the highly radiating products of combustion, CO_2 and H_2O, is increased in the furnace atmosphere. For heating operations these two factors lead to a higher heating rate, fuel savings, lower CO_2 emissions and, if the fuel contains sulphur, lower SO_2 emissions, today's best air-fuel solutions need at least 1.3 GJ to heat a tons of steel to the right temperature for rolling or forging [6].

6. Concluding Remarks

The following conclusions have been drawn from the above studies:

- Air fuel mixture has an overall heating thermal efficiency of 50-60% whereas an oxyfuel (with flame) provides 80%.
- With flameless oxy-fuel, not only does the overall thermal efficiency of heating increase but also fuel consumption or saving of energy in a reheating process is at least 26% at times and frequently it may be even more than 60% compared to air-fuel.
- It is possible to operate a reheat furnace with fuel consumption below 1 GJ per tons with up to 50% reduction in CO_2 emissions and substantial savings in NO_X emissions.
- It has been seen that flameless oxyfuel combustion has many considerable advantages over conventional oxyfuel and many more over any kind of air-fuel combustion such as the fact that improved uniformity of temperature distribution in turn, reduces further fuel consumption.
- In our station, oxy-fuel solutions are used in forge shops, annealing operations and ladle pre-heating. They have improved operational flexibility, heating performance and temperature uniformity while reducing scale formation and also reducing fuel consumption.
- Flameless oxyfuel increased the throughput rate up to 50% and increased production using few furnaces in operation thus providing increased flexibility.
- That means it uses only two furnaces and that these are enough to cover the production work of 3 furnaces thus resulting in decreased fuel consumption.

- Increased capacity can also be used to prolong soaking times. Thanks to the reduced time at elevated temperatures, oxyfuel leads to reduced scale losses, at many installations as high as 50%.
- In the present study, vessel preheating and ladle preheating using flameless oxyfuel, showed considerable benefits with very good economic output.

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