Heat transfer enhancement in an air process heater using semi-circular hollow baffles

Aashique Alam Rezwan*, Sarzina Hossain, S M Ashrafur Rahman and MA Islam

Department of Mechanical Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

Abstract

Air process heater is one of the crucial equipment for many industries. Process heater is used in Baking, Drying, Laminating, Metal Working, Packaging, Plastic Welding, Preheating, Sealing, Soldering, Shrink Fitting, Synthetic Fabric Sewing and in other industries. But heating of air to a very high heat flux is sometimes impossible without the degradation of air quality, because many industries use combustion of gases for the purpose of heating the air to a very high heat flux. Electric heater can be alternative heating equipment, but it requires costly and long heating apparatus for the desired air temperature. In the present study, heat transfer enhancement in an air process heater was investigated both numerically and experimentally. A circular duct with 5 semi-circular hollow baffles and 4 cartridge electric heaters was designed for the process heating. Air was supplied from a wind tunnel at 3.17×10^4 Reynolds number. Total supplied electric power was 3 kW. The results showed the temperature ratio (Ambient Temperature/Air Temperature) to be decreased up to 0.72 where in many electric air heaters the temperature ratio is about 0.9. The designed air process heater supplies air at velocity 19 m/s and temperature up to 147ºC. The experimental results were also matched with the numerical simulation values of the designed heater. The results were also compared with some of the existing air process heater for investigating the enhancement of heat transfer.

Keywords: Air process heater; heat transfer enhancement; baffle; cartridge heater

1. Introduction

Air process heater is important equipment in many industrial applications. Process heater is used in Baking, Drying, Laminating, Metal Working, Packaging, Plastic Welding, Preheating, Sealing, Soldering, Shrink Fitting, and Synthetic Fabric Sewing and in other industries. But heating of air to a very high heat flux is sometimes impossible without the degradation of air quality, because many industries use combustion of gases for the purpose of heating the air to a very high heat flux.

In the present study, a simulation approach has been conducted to increase the efficiency of the air process heater within size limit. The principle goal of the project is to design a heater that can be used to heat the air from a blower with certain velocity. The length of the heater is also a factor to be considered. The target length of the heater was given to be within 2 feet. Different types of combinations have been considered for the design, including using nirome wire heater. But the calculated value showed that most of them can’t be used due to inefficiency of heating to the air within the target range. Thus for better understanding and design, many complex geometry like series heater, heating by suddenly slowing down the air etc., has been simulated and compared. After several considerations finally the design with semi-circular hollow baffle showed a comprehensive improvement of the heating process within the target range.
Previously, similar type of heating system has been developed by MAT Ali and Hasan [1-2], but the capacity of the heating system is low compared to the present design [3]. Many other researchers has been experimented about the proper condition of an air process heater. Siviryuk et al. [4] has developed and diagnosis method for the air process heater, Vikhman et al. [5] has presented a technical and economic rationale for selecting an air process heater. The design process and the comparison of simulated value and the experimental value of the fabricated heater are described. The heater has been fabricated using the local available material and equipment, and the total fabrication has been done under the authors’ supervision. The local availability of material and cost are also taken into consideration for the final design.

2. Design of heater

Figure 1 shows the different parts of the heater section. The overall length of the heater section is 0.9 m. It consists of 4 cartridge heaters of total power consumption of 3 kW. Five half circular baffles are placed in series in the heating section to enhance the heating capacity of the air. Air from the wind tunnel is passed through the entrance section, heating section and settling chamber and then finally through the nozzle to produce the desired jet of air.

Swirling effect of the air due to the baffles ensures the uniform heating of air from the heater surface. The heated air then passes through the long settling chamber to the nozzle having a diameter of 25.4 mm. This is to note that the settling chamber is insulated with asbestos cloth and heat tape to prevent the heat loss to the surrounding from the hot air.
3. Simulation of the air process heater

For designing the heater computer simulation has been used. In the present works, ANSYS CFX has been used to simulate the air flow and heating process in the heater section. Figure 3(a) shows the contour plot of air temperature through the heater section. It can be seen that the swirling effect of the baffle greatly enhance the heating process.

![Temperature contour plot](image)

Fig. 3. (a) Temperature of air through heater section (b) heater surface temperature

In the fig. 3(b) the surface temperature of individual cartridge heater has been showed. This measurement is required for the safe heating of air. Due to the lack of heat transfer capability of air, the confined air in the section does not heat up properly. If the air near the surface of the heater can’t transfer heat to the surrounding air in the section, the surface of the cartridge heater will be increase due to the lack of heat transfer. If the temperature increases in excess of the safe temperature for the heater, the heater could be break. Fig. 4 shows the mid line air temperature along the heater section.

![Diagram of heater section](image)

Fig. 4. Temperature of air (mid line) along the heater section
4. Experimental setup

The experimental study has been carried out by using a circular air jet facility as shown in Fig. 5. Detail explanation of different segment of the facility has been given in the previous studies [1-2]. The overall length of the flow facility is 9.0 m. It has axial flow fan unit, two settling chambers, two diffusers, a silencer and a flow nozzle. The fan unit consists of three Woods Aerofoil fans of the same series. The fan unit receives air through the butterfly valve and discharges it into the silencer of the flow duct. Flow from the silencer passes on to the settling chamber through a diffuser. At the discharge, side of this chamber there is a flow straightener and wire screen of 12 meshes to straighten the flow and to breakdown large eddies present in the air stream. Air from this chamber then flows to the second settling chamber through a nozzle and second diffuser. The flow straightener and wire screens are used here to ensure a uniform axial flow free of large eddies which may be present in the upstream side of the flow. The flow from the second settling chamber then enters the 100 mm long and 80 mm diameter circular nozzle. At the farthest end the diameter of the flow facility is reduced from 475 mm to 88.9 mm where the heating section is placed [1-2].

![Fig. 5. Wind tunnel for the circular jet facility [1]](image)

The air flow through the nozzle is controlled by regulating the speed of the fan units. The temperature of the jet is regulated by controlling the supply voltage of the heater. The whole setup is mounted on rigid frames of M.S. pipes and plates and these frames are securely fixed with the ground so that any possible unwanted vibration of the system is reduced to a minimum. To avoid the effect of ground shear, the setup is installed at an elevation of 1.4 m from the ground.

5. Results and discussions

To ensure that the designed heater has been performing up to the requirement the heater section has been tested to its limit and compare with the computer simulation. Figures 6(a) depict the air jet temperature and fig. 6(b) temperature ratio of the jet of air for the increasing electrical energy input. With the increasing input energy the temperature of the jet of air increases exponentially. The surface temperature of the heater section (Fig. 6c) has been determined for the safety of the cartridge heater as described in the previous section. Then the experimental result has been compared with the computer simulation result. Fig. 7 shows the comparison between experimental result and the computer simulation result.

![Fig. 6 (a) Temperature of air jet with electrical energy input and (b) temperature ratio with electrical energy input](image)
From the Fig. 7 it can be seen that at low power input, the temperature of air for the computer simulation is quite greater than the experimental result. As the power input increases, the difference between the two values also decreases and become equal at the rated condition for safe limit of the heater. After that, the experimental value of the temperature is increases more than the computer simulation result. This may due to the heat loss at low power, as there is cooler air in the surrounding. At high power input, as the time of heating increases, the temperature of the baffles and the pipe also increases. This restricts the air to loose heat to the surrounding environment.

Table 1. Summary of previous & designed air jet heater section [2]

| Comparison Criteria          | Previous Heater [2]                  | Designed & Constructed Heater |
|------------------------------|--------------------------------------|--------------------------------|
|                              | Electric Resistance Wire and Mica Sheet | Cartridge Heater 1200W (each) |
| Heater Type                  |                                      |                                |
| Number of Section            | 4                                    | 3                              |
| Number of Heaters            | 6                                    | 4                              |
| Maximum Design Capacity      | 3 kW                                 | 3 kW                           |
| Maximum Capacity             | -                                    | 4.8 kW                         |
| (maximum)                    | 54°C                                 | 136°C                          | 147°C                          |
| Maximum Jet Temperature      | 3.72 x 10^4                         | 3.17 x 10^4                    | 3.17 x 10^4                    |
| Intermittent Mixing Capability| Present                             | Present                        | Present                        |
| Temperature Control          | Varying the Supply Voltage           | Given Input                    | Variable Voltage Supply        |
6. Conclusion

An air process heater has been designed and fabricated which can heat the air up to 147°C. The designed Reynolds’ number is \(3.17 \times 10^4\). The surface temperature of the heater has also been determined for the safety limit of the heater. Total supplied electric power was 3 kW. The results showed the temperature ratio (Ambient Temperature/Air Temperature) to be decreased up to 0.72 where in many electric air heaters the temperature ratio is about 0.9. The designed air process heater supplies air at velocity 19 m/s and temperature up to 147°C. The experimental results were also matched with the numerical simulation values of the designed heater. The results were also compared with some of the existing air process heater for investigating the enhancement of heat transfer. This type of heater can be adopted in any industrial process without adulterating the air.

References

[1] Ali, M. A. T., Bhattacharjee, S., 2009, “Experimental Study of Thermally Stratified Co-Axial Jets with Trip Ring Excitation”, Proc. Int. Conf. on Mechanical Engineering (ICME2009), Dhaka, Bangladesh.

[2] Hasan, M. N., 2008, “Experimental Study of Flow Characteristics in the Near Field of a Thermally Stratified Co-axial Free Jet”, M.Sc. Thesis, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh.

[3] Islam, MA, Rezwan, A.A., Hossain, S. and Islam, AKMN, 2011, “Study of Transient Heat Transfer of Solid with Protective Fabric Under Hot Air Jet Impingement”, Proc. Int. Conf. on Mechanical Engineering (ICME2011), Dhaka, Bangladesh.

[4] Siviryuk, V.L., Gramotnik, I.V., and Bezrukov, A.,N., 2011, “Diagnostics of The Air-Heater Casings in Blast Furnaces.”, Steel in Translation, Volume 41, Issue 1, pp36-40.

[5] Vikhman, A.,G. and Kharichko, M.,A., 2006, “Selecting an Air Heater. Technical and Economic Rationale.”, Chemistry and Technology of Fuels and Oils, Volume 42, Issue 4, pp 262-270.