Design and Fabrication of Compact Economizer for Waste Heat Recovery of VCR Engine

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Abstract—This report represents the development of Design and Fabrication of compact Economizer for Waste Heat Recovery of VCR Engine . The economizer serves as a vital component in thermal systems, engineered to recover waste heat from exhaust gases and enhance overall energy efficiency. The study outlines an integrated approach involving the design, manufacturing, and performance optimization of the economizer for industrial boiler applications. The development process involved multiple stages, including equipment selection, data collection, cost considerations, and performance evaluation. Initially, the necessary components for the economizer were sourced, followed by the assembly of the economizer model. Through the assembly process, the modeling of the economizer structure became clearer and more efficient. Key components such as stainless steel sheets, fins, tubes, headers, and coil buffers were gathered to construct the system. Stainless steel was used for the outer body, which required bending and shaping operations performed with the assistance of industry professionals. Subsequent fabrication included the formation of inlet and outlet headers involving welding and outlet connections. Finishing operations were carried out to ensure structural integrity. The casing was then fabricated to precise dimensions, into which the components were accurately installed. The final stages included welding, machining, forming, and application of protective coating to improve durability and operational efficiency.

Index Terms— **Tube, Baffle Plate, Casing, Inlet Header, Outlet Header, Saddle, insulation Material (Mineral wool).**

I. INTRODUCTION

In the modern industrial world, energy efficiency is a vital factor for the sustainability and cost-effectiveness of thermal systems. A significant amount of heat energy is lost through the exhaust gases of boilers and other heat-generating equipment. To minimize this loss, an economizer—a type of heat exchanger—is used to recover waste heat by preheating the feedwater before it enters the boiler. This process reduces the overall fuel consumption and enhances thermal efficiency. This not only enhances the thermal efficiency of the system but also reduces fuel consumption and emissions, contributing to both economic and environmental benefits.

This project focuses on the design, manufacturing, and analysis of an optimized economizer aimed at improving its performance and efficiency. The system primarily consists of metal tubes, a support frame, inlet and outlet connections, and a gas flow chamber. As hot flue gases pass over the surface of the tubes, heat is transferred to the water flowing inside, increasing its temperature and reducing the energy required for boiling.

To achieve better heat transfer and lower pressure drops, key design parameters such as tube material, geometry, and arrangement are optimized. The final design aims to deliver improved heat recovery while maintaining structural stability and cost-effectiveness. This optimized economizer can be effectively used in both industrial and commercial boiler systems, supporting energy conservation and reducing operational expenses.

The necessity of this project lies in enhancing energy efficiency by optimizing the economizer design to recover more heat from exhaust gases, which directly leads to fuel savings and improved boiler performance. By capturing waste heat, the fuel required to generate steam is reduced, lowering both operational costs and harmful emissions. Additionally, focusing on sustainable manufacturing allows the economizer to be produced efficiently, with less material waste and at a lower cost, making it suitable for a wide range of industrial applications. The main objectives of the project are to design and develop a compact economizer, fabricate a small-scale model for experimental analysis, study the effects of varying flue gas velocity, and conduct thermal analysis using ANSYS software to evaluate performance and optimize the design.

II. SYSTEM DEVELOPMENT

In India, the role of economizers in improving thermal efficiency and reducing energy consumption in steam generation systems has been the subject of extensive research. This section presents a critical review of previous studies focusing on economizer design, material selection, computational analysis, and optimization techniques.

1. Design of Economizer

Create a detailed design plan for the economizer, considering factors like size, material, and efficiency requirements. Material selection: Choose suitable materials such as stainless steel, carbon steel, or alloys based on factors like temperature, pressure, and corrosion resistance. Fabrication: Cut, bend, and shape the selected materials according to the design specifications using techniques like welding, machining, and forming. Assembly: Assemble the fabricated components into the final economizer structure, including attaching tubes, headers, fins, and other necessary parts.

2. Welding of Economizer

Part of economizer fabrication, as it ensures strong and leak-proof joints between tubes, headers, and stubs. Common welding methods used include TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas) welding, which provide high-quality and precise welds.

The materials used in economizers, such as carbon steel or stainless steel, require proper welding techniques to handle high pressure and temperature conditions. Weld quality is checked through non-destructive testing (NDT) methods like ultrasonic or radiographic inspection to ensure there are no cracks, porosity, or weak spots. Proper welding not only ensures safety and durability but also enhances heat transfer efficiency by maintaining clean and smooth internal surfaces.

3. Comparative Advantages and Limitations

Economizers come in different types, each with their own benefits and drawbacks. Bare-tube economizers are cheaper and easy to clean but offer lower heat transfer. Finned-tube economizers improve efficiency by increasing the surface area, but they are harder to clean and cost more. Spiral-finned tubes perform well in small spaces but are more complex to make. In terms of layout, staggered tube arrangements give better heat transfer than inline ones but cause higher pressure drop. For materials, carbon steel is low-cost but not good against corrosion, while stainless steel lasts longer in harsh conditions but is more expensive. Choosing the best design depends on performance needs, cost, and working conditions.

4.Main components of Economizer

4.1. Tube

Overview: Tubes are the most essential components in an economizer, as they facilitate the transfer of heat from hot flue gases to the boiler feedwater. The performance and efficiency of the economizer largely depend on the material, size, and arrangement of these tubes. Typically, mild steel, carbon steel, or stainless-steel tubes are used due to their good thermal conductivity and ability to withstand high temperatures and pressure.

Fig. 1 Tube

4.2. Baffle Plate

Overview: baffles help in reducing cold spots, improve temperature uniformity, and can minimize fouling or soot deposition by controlling gas velocity. The placement and spacing of baffles must be carefully designed, as too many baffles can cause a highpressure drop, while too few may lead to poor heat recovery. By optimizing baffle design, the overall thermal efficiency of the economizer can be significantly improved without compromising structural stability or gas flow characteristics.

Fig. 2 Baffle Plate

4.3. Casing

Overview: The casing in an economizer serves as the outer protective enclosure that houses the entire heat exchanger assembly, including the tubes, baffles, and flue gas passages. Its primary function is to contain and direct the flow of hot flue gases so that maximum heat transfer can occur between the gases and the water inside the tubes. The casing also prevents heat loss to the surroundings, thereby improving the overall thermal efficiency of the system.

Fig. 3 Casing

4.4. Inlet Header

Overview: The inlet header in an economizer plays a crucial role in the distribution of feedwater into the heat exchanger tubes. It acts as a central manifold where the incoming cold water from the boiler feed pump enters before being directed uniformly into multiple tubes.

Fig. 4 Inlet Header

4.5. Outlet Header

Overview: The outlet header in an economizer is a key component responsible for collecting the heated feedwater from all the individual heat exchanger tubes after it has absorbed thermal energy from the flue gases. the outlet header ensures that the heat recovered by the economizer is effectively delivered to the next stage of the boiler, contributing directly to improved boiler efficiency, reduced fuel consumption, and energy savings.

Fig. 5 Outlet Header

4.6. Saddle

Overview: The tube bundles and are installed at specific intervals to distribute the weight evenly and prevent bending or sagging of the tubes due to thermal expansion or vibrations. Saddles help maintain alignment and spacing between the tubes, ensuring consistent gas flow and heat transfer performance.

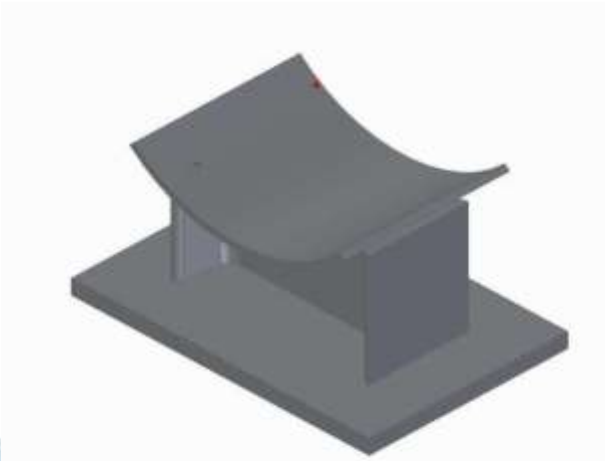

Fig. 6 Saddle

4.7. Water inlet /outlet stub

Overview: The inlet stub allows cold feedwater to enter the economizer, where it absorbs heat from the flue gases. After heating, the water exits through the outlet stub and flows into the boiler. These stubs are usually made from strong, heat-resistant materials like carbon steel or stainless steel to handle high pressure and temperature.

4.8. Gas inlet /outlet stub

Overview: The gas inlet and outlet stubs are important components of an economizer that manage the flow of hot flue gases. The gas inlet stub allows the hot exhaust gases from the boiler or furnace to enter the economizer. As the gases pass over the heat exchange tubes, they transfer heat to the feedwater flowing inside the tubes. After giving up their heat, the cooler gases exit the economizer through the gas outlet stub and are released to the chimney or further emission systems.

4.9. Insulation

Overview: Thermal insulation material for heat exchangers due to its excellent high-temperature performance, low thermal conductivity, and fire resistance. The material is typically applied to the external surfaces of shell-and-tube heat exchangers, air preheaters, or economizers to minimize heat loss, improve energy efficiency, and protect equipment from thermal stress.

III.HEAT AND MASS BALANCING

Heat balancing involves calculating the amount of heat transferred from the exhaust gas to the water. It is done using the formula $Q = m \times Cp \times \Delta T$, where m is mass flow rate, Cp is specific heat, and ΔT is the temperature difference.

- Gas Side – 9.5kg/hr
- Gas Inlet Temp [T2] – 180 °C……. [Disel engine gas outlet]
- CP of Gas at Inlet – 1.115kJ/kg……… [Use in industrial boiler book]
- Gas Outlet Temp [T1] – 171 °C……………. Assumed
- CP of Gas at Inlet – 1.113kJ/kg……… [Use in industrial boiler book]
- Q gas = m*cp. (temperature difference)
  = 9.5/3600*((180*1.115) - (171*1.113))
  = 0.028kj/s

Water Outlet Temperature Calculation:

- Water Side = 240*3600/1000*60
  = 14.4kg/hr
- Water Inlet Temp [T2] – 25 °C……… [Atmosphere pressure]

- Specific Of Water = 4.187kj/kg k
- Q = 0.028kj/s
- Water Outlet Temp = [Q/(w/3600) +Water Inlet Temp]
  = [0.028/ (14.4/3600) +25]
  = 31.1°C

The Log Mean Temperature Difference (LMTD)

A key parameter used to calculate the heat transfer in heat exchangers, representing the average temperature driving force between the hot and cold fluids.

A parallel flow heat exchanger, both fluids enter the exchanger from the same end and flow in the same direction.

- LMTD Parallel = [(T2-T3) -(T1-T4)/In[(T2-T3)/(T1-T4)]
  = [(180-25) -(171-31.9)/In [(180-25)/ (171-31.9)]
  = 146.91 °C

A counterflow heat exchanger has the hot and cold fluids entering from opposite ends and flowing in opposite directions.

- LMTD Counter = [(T1-T3) -(T2-T4)]/In[(T1-T3)/(T2-T4)]
  = [(171-25) -(180-31.9)]/In [(171-25)/ (180-31.9)]
  = 147.05 °C

Geometry : Proper geometric design ensures not only efficient heat transfer but also mechanical reliability and ease of operation.

- Avg. Gas Temp. =Gas inlet Temp.+ Outlet Temp./2
  =(180+171)/2
  =175.5 °C
- Sp. Heat (c) = 1.11392kj/kg k
- Dynamic Viscosity (μ) = 0.0000°C
- Thermal cond. (k) =0.03481 w/mk
- No. of tubes wide = 2
- No. of deep =2
- Tube Outer Diameter = 12mm
- Tube Thickness = 1.8mm
- Tube Length = 245mm
- No. of pass = 3
- Length per pass = 81.7mm
- Equivalent diameter = 4A/ P
  = 4[170*92]/[2*170+92]
  = 120mm
- Trans. Pitch = 50mm
- Long. Pitch = 50mm
- Available Area = π*OD*Length*No.of Tube Wide*No of Tube Deep/10^6
  = π*12*245*4*2/106
  = 0.074m^2

Area required: The area required in a heat exchanger depends on the amount of heat to be transferred, the overall heat transfer coefficient, and the log mean temperature difference (LMTD) between the hot and cold fluids. A larger surface area is needed when the heat transfer rate is high, the temperature difference is small, or the heat transfer coefficient is low to ensure efficient thermal performance.

- Flow area = 170 *90*10^{-6}
  = 0.015 m^2
- Gas mass velocity (v) = gas side / flow area*3600
  = 9.5/0.015 *3600
  = 0.17 kg/m^2s
- Velocity of gas = (V)/ρ
  = 0.17/0.782
  = 0.221 m/s
- Re = Gd/μ
  = 0.17*120*10^3/0.00002
  = 875.49

- Pr = μCp/k
  = 0.00002*1.11392*1000/0.03481
  = 0.76

- Nu = 0.33*Re^0.6*Pr^0.33
  = 0.33*875.49^0.6*0.76^0.33
  = 17.53

- ho = (Nu*k/equivalent dia. *10^-3)
  = (17.53*0.034/120*10^-3)
  ho = 5.09 w/m^2k

- hi (Inside heat transfer coefficient) = 500 w/m^2k

- Over all HTC(U) = (1/((1/ho) +(1/hi)))
-
  = (1/((1/5.09) +(1/500)))
  = 5.035 w/m^2k
- Area required = Q (gas)*1000/Over all HTC * LMTD (counter flow)
  = 0.028*1000/5.035*147.05
  = 0.074 m^2

Fig. 7 Front View of Economizer

Fig. 8 Side view of Economizer

Fig. 9 Insulated assembly

IV. CONCLUSION

1. The design, construction and evaluation of an Economizer were successfully carried out.
2. The new concepts can be implemented and the Economizer can be modified as per demand or requirement.
3. Waste heat of exhaust gases can be effectively used for heating the process water
4. The fuel cost is saved by use of machine up to 30%.

5. The without insulation temperature rise of 5deg.C is achieved for water at the flow rate of 240ml/min.

6. The with insulation temperature rise of 50deg.C is achieved for water at the flow rate of 240ml/min.

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