A New Approach to Waste Heat and Pressure Energy Systems

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Abstract
The industrial sector consumes about 1/3 of the total energy in the world and is responsible for 1/3 of the fossil fuel related green house gas emissions. According to current estimates somewhere between 20 to 50% of the total energy input is lost in the form of waste heat and pressure energy of exhaust gases, losses from hot equipment surfaces etc. Continuous efforts of the industrial sector to improve its energy efficiency and to recover waste heat losses provide a lucrative opportunity for developing an emission free and less costly energy resource. Numerous techniques have been studied and employed for utilization of waste heat and pressure energy in industries. Effectiveness of a method in energy recovery depends upon the enthalpy and pressure of waste source and the economics of method. This paper aims to study various sources of waste heat and pressure energy and analyze the effectiveness of a counter flow vortex tube applied to recover waste energy. This relatively new technique is explored to enhance economic feasibility and increase recovery efficiency of waste heat and pressure energy in current industrial practices. This study attempts to improve waste heat recovery technologies. Various applications of vortex tube are listed according to the source of available energy like refrigeration, spot cooling, space cooling, gas enrichment etc. A bottom-up approach is used to analyze quantity and quality of waste energy, recovery methods and hurdles in path of improving their efficiency. The results from this analysis help to understand the state of waste heat and pressure energy and recommend redesign of energy recovery mechanisms.

Keywords

I. Introduction
Waste heat energy and waste pressure energy are two main sources of waste energy in current industry scenario. In this paper these terms are used synonymously as in most cases waste energy includes both heat and pressure energies. Waste energy refers to the energy generated in any industrial process but is released into environment without utilizing it to full value. Common forms in which waste heat and pressure energy is available are hot exhaust gases, used up steam, compressed air and hot water [1]. In any industry economic analysis and efficiency calculations related to production of waste energy are very important. It aids in figuring out the energy losses and identifying the control measures that can be applied. Various sources producing waste heat and pressure energy are reviewed in this paper and application of a vortex tube setup to generate temperature difference from these waste energy sources according to input pressure is analysed.

II. Waste Energy Sources
A large number of industrial processes produce waste heat energy. Some of these which can act as major waste heat and pressure energy sources are tabulated below:

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>TEMPERATURE (°F)</th>
<th>PRESSURE (bar)</th>
<th>APPLICATION OF WASTE ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine exhaust</td>
<td>700 – 1000</td>
<td>6 - 100</td>
<td>Electricity production,</td>
</tr>
<tr>
<td>Blast furnace exhaust</td>
<td>1650 – 3000</td>
<td>6 – 10</td>
<td>Steam generation for mechanical process</td>
</tr>
<tr>
<td>Envelope furnace exhaust</td>
<td>1400-1800</td>
<td>6.5 - 10</td>
<td>Combustion air pre-heat</td>
</tr>
<tr>
<td>Air furnaces, sintering furnaces exhaust</td>
<td>1200</td>
<td>2 – 5</td>
<td>Furnace load preheating</td>
</tr>
<tr>
<td>Geothermal steam</td>
<td>212</td>
<td>6 – 8</td>
<td>Feed water heating</td>
</tr>
<tr>
<td>Thermal power plant gas exhaust</td>
<td>550-900</td>
<td>5 – 30</td>
<td>Furnace load preheating, Feed-water preheating</td>
</tr>
<tr>
<td>Steam boiler exhaust</td>
<td>450 – 900</td>
<td>3-5</td>
<td>Combustion air preheat</td>
</tr>
<tr>
<td>Reciprocating engine exhaust</td>
<td>600 – 1100</td>
<td>2-5</td>
<td>Transfer to low temperature processes</td>
</tr>
<tr>
<td>Cooling water from engines, compressors, furnace doors</td>
<td>80 – 450</td>
<td>-</td>
<td>Space heating, Domestic water heating</td>
</tr>
</tbody>
</table>

III. Waste Energy Recovery
First step to be taken is to reduce the waste energy production to minimum. This can be done by increasing process efficiency and reducing losses but waste energy below a certain level is unavoidable and thus various techniques are employed for recovery of this waste energy. The technique that should be applied to recover waste heat and pressure energy depends upon the pressure, temperature and quantity of the source and the type of fluid exhausted. The conventional objective of waste energy recovery is electricity generation from high pressure exhaust gases from furnaces and engines [2]. Methods for waste heat and pressure recovery include transferring heat between gases and
liquids, transferring heat to the load entering furnaces, generating mechanical and/or electrical power, or using waste heat with a heat pump for heating or cooling facilities and piezoelectric generation.

Some common applications of waste heat and pressure energy are listed below [3]:
1. Combustion air preheating
2. Boiler feed-water preheating
3. Load preheating
4. Power generation
5. Steam generation for mechanical work
6. Space heating
7. Transfer to liquid or gaseous process streams

IV. Factors Affecting Recovery Feasibility

A. Heat Quantity
The net heat content of a stream is termed as its heat quantity while quality is a measure of the usefulness of the waste heat. Heat quantity depends upon the mass flow rate, heat capacity and the temperature of the fluid.

\[ E' = m'C'T \]

Where  
- \( E' \) = waste heat loss per unit time
- \( m' \) = mass flow rate of fluid stream
- \( C' \) = specific heat of fluid
- \( T' \) = temperature of stream

It must be noted that enthalpy is not an absolute term, but must be measured against a reference state.

B. Temperature
Temperature of the source determines its quality and the method to be applied. It defines the physical state of stream establishing its effectiveness as a waste energy source. For example superheated steam is a better quality source than wet steam for same pressure.

C. Pressure
Pressure of the working fluid is of prime importance. High pressure sources provide more energy but usually require costlier recovery setups. Pressure is the key factor for determining the efficiency of recovery in processes like piezoelectricity generation and vortex tube application.

V. Application of Vortex Tube for Energy Recovery

A vortex tube also known as the Ranque - Hilsche tube, is a device that separates a stream of gas into two streams simultaneously, one at a higher temperature and other at a lower temperature than input stream. It is a simple three end tube having no moving parts and does not require any energy input for operation. Vortex tube is applicable to various situations where simplicity and robustness are required. Vortex tube is used for space heating and cooling, cooling circuits and weld spots etc [4]. The inlet nozzles are tangential to the main tube in order to impart vortex motion to the entering gas. The fixed flow restriction on one side of inlet is termed as the cold orifice while at the other end of the main tube is a variable flow restriction called the hot fraction control valve [5]. The stream coming out of orifice is colder than the input stream and the stream coming from the valve is hotter. The temperature deviation is controlled by varying the relative amounts of flow through each side with the help of control valve [6]. Higher the cold stream flow higher its temperature. Fraction of air coming out of cold end is called cold mass fraction and fraction of air coming out of hot side is called hot mass fraction.

The vortex tube works as a plain energy separating device. Redistribution of energy takes place through vortex generation without any external heat exchange or work [7]. The input stream gets divided into two streams, one of higher energy than surrounding fluid and other of lower energy [8].

VI. Evaluation
Experimental results for a vortex tube setup recorded with varying input stream pressures are provided below [9].

<table>
<thead>
<tr>
<th>Tube dia (mm)</th>
<th>Cold end dia (mm)</th>
<th>Inlet dia (mm)</th>
<th>Nozzle Dia mm)</th>
<th>Length of cold tube (mm)</th>
<th>Length of hot tube (mm)</th>
<th>Hot end angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>120</td>
<td>30</td>
<td>45</td>
</tr>
</tbody>
</table>

A. Experimental Setup

![Experimental Apparatus](image-url)
1. Compressed air Receiver,
2. Hand operated Valve,
3. Pressure gauge,
4. Counter flow Vortex Tube,
5. A set of orifice flow meters,
6-7. Orifice Flow meter,
9. Cone-shape valve

The tube was selected such that large range of pressures could be tested. Experiments with different tubes were also carried out but only the most efficient results obtained from the tube of stated dimensions are used here. The experiments were conducted for analysis of counter flow vortex tubes and the results were used to study effectiveness of vortex tubes to various sources of pressurized gases. The results here are for pressures 0-10 bar as it is evident from Table 1 that most sources come fall in this range.

Results

Observations at a constant pressure of 4 bar

Fig. 3: Temperature Fraction ($\varepsilon$) Hot End ($\Delta T_h$) as a Function of Cold Air Mass Fraction ($\varepsilon$)

Fig. 4: Temperature Drop at Cold End as a Function of Cold Air Mass Fraction ($\varepsilon$)

Fig. 5: Heating Effect of Vortex Tube is a Function of Cold Mass Fraction ($\varepsilon$) at inlet Pressure 4 Bar

B. Observations at Varying Pressure (0-10 bar)

Experimental results for pressures varying from 0-10 bar give substantial temperature splitting at hot and cold ends. Thus it is evident that vortex tubes with proper design can be applied to various sources providing waste energy in the form of pressurized gases.

Fig. 6: Temperature Drop at Cold End (°C) as a Function of Inlet Pressure (bar)

Fig. 7: Refrigerating Effect as a Function of Cold Air Mass Fraction (ε) at Inlet Pressure 4 bar

Several applications of vortex tubes can be gained through its coupling with waste energy systems.

Table 3: Application of Vortex Tubes

<table>
<thead>
<tr>
<th>Application</th>
<th>End of Tube used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling of hotspots</td>
<td>Cold end</td>
</tr>
<tr>
<td>Space heating</td>
<td>Hot end</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>Both ends</td>
</tr>
</tbody>
</table>

VII. Discussions

This study lists the potential sources of waste heat and pressure energy. The importance of developing waste energy recovery mechanisms and the need for better recovery models is emphasized upon. Most of the major heat and pressure energy sources provide energy in ranges that can be easily harnessed using newer technologies like vortex tube setups. Major technical problem with current energy recovery modes is varying pressures and temperatures of gases used as working agent [10]. Thus extensive design is required that accommodates sufficient range of these parameters. Another hindrance in energy recovery optimization is bulky size of setups like auxiliary steam generation unit and steam turbines [11]. Large size of recovery setup leads to higher costs and complex maintenance measures.

Since, pressures of many waste energy sources fall in range of 0bar to 10bar, therefore applicability of vortex tube is high as an energy recovery mechanism. Robustness of this method, simple design and small size as compared to other methods proves it as a better alternative. Yet application of vortex tube to energy recovery at a large scale is obstructed by its dependence on inlet temperature and design specificity. It is difficult to design tube
to work at high operating temperatures. A probable solution to the problem can be multistage flashing of source, where vortex tube is attached at later stages where temperatures are within its working range.

VIII. Conclusion

The data above elucidates the need of better and newer energy recovery methods and to increase the efficiency of systems by harnessing maximum energy from waste sources. Design of newer mechanisms like vortex tube setups will help to achieve a superior energy scenario.

References


Upendra S. Gupta received his B.E degree in mechanical engineering from S.G.S.I.T.S, Indore, India, in 2005, the M.E (Gold Medalist). Degree in Design & Thermal Engg. from IET DAVV, Indore, India in 2010. Before teaching he worked in Gajra Bevel Gears corporation as an engineer for 1 year from march-98 to october-99 and at Tapasya Engg. ( STPS Sarni) till 2002. He is currently at Reader’s position in S.V.I.T.S, Indore. His research interest include thermal engineering design, applications of vortex tube, CFD, Nano-technology, power transmission and has successfully published his research in these topics. He has received Gold medal from the governor of MP In DAVV Dikshant Shamoroh 2013 for his research work.