International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 12, December 2016
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

REVIEW OF DIFFERENT WASTE HEAT RECOVERY DEVICES IN PROCESS INDUSTRY

H. A. Phadtare[1], I. H. Patel[2], V.N. Mahindrakar[3]

[1]*Department of Mech. Engg, COE Malegaon, Bk (India)*
[2]*Department of Mech. Engg, COE Malegaon, Bk (India)*
[3]*Department of Mech. Engg, COE Malegaon, Bk (India)*

ABSTRACT

As a result of depleting reserves of fossil fuels, conventional energy sources are becoming less available. In spite of this, energy is still being wasted, especially in the form of heat. The energy efficiency of process sites (defined as useful energy output per unit of energy input) may be increased through waste heat utilisation, thereby resulting in primary energy savings. In this work, waste heat is defined and a methodology developed to identify the potential for waste heat recovery in process sites; considering the temperature and quantity of waste heat sources from the site processes and the site utility system (including fired heaters and, the cogeneration, cooling and refrigeration systems). Benefits of waste heat recovery systems are discussed, furthermore salient points required for development of waste heat recovery system. Review of different waste heat recovery devices is taken, along with different case example. The review work also shows that combining technologies into a system creates greater potential to exploit the available waste heat in process sites

Keywords- Heat Pipes, Heat Wheels, Recuperators, Regenerators, Waste Heat.

I. INTRODUCTION

1.1 Introduction

Waste heat utilisation has received interest in recent years due to energy sources becoming less available and there is potential in waste heat to improve the energy efficiency of process sites.Waste heat loss isQuality-Depending upon the type of process, waste heat can be rejected at virtually any temperaturefrom that of chilled cooling water to high temperature waste gases from an industrial furnaceor kiln. Usually higher the temperature, higher the quality and more cost effective isthe heat recovery. In any study of waste heat recovery, it is absolutely necessary that thereshould be some use for the recovered heat. Typical examples of use would be preheating ofcombustion air, space heating, or pre-heating boiler feed water or process water. With hightemperature heat recovery, a cascade system of waste heat recovery may be practiced toensure that the maximum amount of heat is recovered at the highest potential. An exampleof this technique of waste heat recovery would be where the high temperature stage wasused for air pre-heating and the low temperature stage used for process feed water heatingor steam raising.Quantity- In any heat recovery situation it is essential to know the amount of heat recoverable and alsohow it can be used.

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

1.2 Classification & Application

In considering the potential for heat recovery, it is useful to note all the possibilities, andgrade the waste heat in terms of potential value as shown in the following Table 1.

High Temperature WHR

The following Table 2 gives temperatures of waste gases from industrial process equipment in the high temperature range. All of these results from direct fuel fired processes [5].

Medium Temperature WHR

The following Table2 gives the temperatures of waste gases from process equipment in the medium temperature range. Most of the waste heat in this temperature range comes from the exhaust of directly fired process units.[5]

Table1Waste Source & Quality

No.	Source	Quality
1.	Heatinfluegases.	highertemperature,greaterpotentialvalueforheat recovery
2.	Heatinvapourstreams.	Asabovebutwhencondensedlatentheatalsorecoverable.
3.	Convective&radiantheat lostfromexteriorof equipment	Lowgrade–ifcollectedmaybeusedforspaceheating/airpreheats.
4.	Heatlossesincoolingwater.	Lowgrade–usefulgainsifheatisexchangedwithincomingfresh water
5.	Heatlossesinproviding chilledwaterorinthe disposalofchilledwater	a) Highgradeifitcanbeutilizedtoreducedemandforrefrigeration. b) Lowgradeifrefrigerationunitusedasaformofheatpump.

Table 2 Temperatures of Waste Gases from Process Equipment

High Temp. Range	
Types of Device	Temperature,°C
Nickel refining furnace	1370–1650
Aluminium refining furnace	650–760
Cement kiln (Dry process)	620–730
Glass melting furnace	1000–1550
Hydrogen plants	650–1000
MediumTemp.Range	
Steam boiler exhausts	230–480
Gas turbine exhausts	370–540
Heat treating furnaces	425–650
Drying and baking ovens	230–600
Annealing furnace cooling systems	425–650
Low Temp. Range	
Process steam condensate	55–88
Bearings	32–88

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Welding machines	32–88
Injection moulding machines	32–88
Internal combustion engines	66–120
Air conditioning and refrigeration condensers	32–43

Low Temperature WHR

The following Table 2 lists some heat sources in the low temperature range. In this range it is usually not practical to extract work from the source, though steam production may not be completely excluded if there is a need for low-pressure steam. Low temperature waste heat may be useful in a supplementary way for preheating purposes.[5]

1.3. Benefits of WHR

Direct Benefits:

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected byreduction in the utility consumption & costs, and process cost.

Indirect Benefits:

a) **Reduction in pollution:** A number of toxic combustible wastes such as carbon monoxidegas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc, releasing to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.

b) **Reduction in equipment sizes:** Waste heat recovery reduces the fuel consumption, whichleads to reduction in the flue gas produced. This results in reduction in equipment sizes ofall flue gas handling equipments such as fans, stacks, ducts, burners, etc.

c) **Reduction in auxiliary energy consumption:** Reduction in equipment sizes givesadditional benefits in the form of reduction in auxiliary energy consumption like electricityfor fans, pumps etc..

II. LITERATURE REVIEW

F. Fathieh et al. [3] discussed determination of the effectiveness of large heat wheelsusing standard measured data and test conditions can be very expensive and time consuming. The main contribution of this paper is that it testsheat wheel components rather than the wheel itself. In addition, this paper deals directly with the question of what accuracy can be achieved for the determination of sensible energy effectiveness by using atransient step change method for the exchanger matrix materials in a test cell.

Tongcai Wang et al. [4] used new type of open-cell metal foam-filled plate heat exchanger based thermoelectric generator system HE-TEG) & proposed to utilize low grade waste heat. Severalimproving methods have been proposed and experimented,including adjustment of the cold water flowrate, enhancement of the heated air inlet temperature and increase of the number of TE couples. The performances of heat exchanger (HE) and thermoelectric generator (TEG) are discussed, respectively

Sarah Brückner et al. [5] investigated the potential of industrial waste heat for heating and cooling applications. Therefore, heat transformation technologies are presented and their technical and economic potentialare

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

discussed. First, different industrial processes and their operating temperatures are presented as possible waste heat sources as well as low temperature processes, which can be supplied with waste heat

T Gbemi Oluleye et al. [6] illustrated methodology for an existing process site using a case study of a petroleum refinery.The energy efficiency of the site increases by 10% as a result of waste heat recovery. If there is an infinitedemand for recovered energy (i.e. all the recoverable waste heat sources are exploited), the site energyefficiency could increase by 33%. The methodology also shows that combining technologies into a systemcreates greater potential to exploit the available waste heat in process sites.

Hongting Ma et al.[7] discussed a great amount of hot waste liquids andgases aredischarged into environment during many steelmaking processes. These waste liquids andgases have crucial energy saving potential, especially for steel slag cooling process. It could be possibleto provide energy saving by employing a waste heat recovery system (WHRS).

A.B. Etemoglu [8] have presented performance analysis of an industrial waste heat-based combined heat and power systems (WHCHP) completely uses energy and exergy efficiency parameters. The effect of waste water mass flow rate, pressure and temperature, organic fluid types on both energy and exergy efficiencies and economical profit of the system is investigated by a computer simulation. The first step of the analysis is the selection of the suitable working fluid. After that, in order to get the performance indicators, different scenarios are run by computer simulation for WHCHP.

III. COMMERCIAL WHR DEVICES

Recuperators- Heat exchange takes place between the flue gases and the air through metallic orceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases is shown in fig 1.The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing as shown in fig. 2.

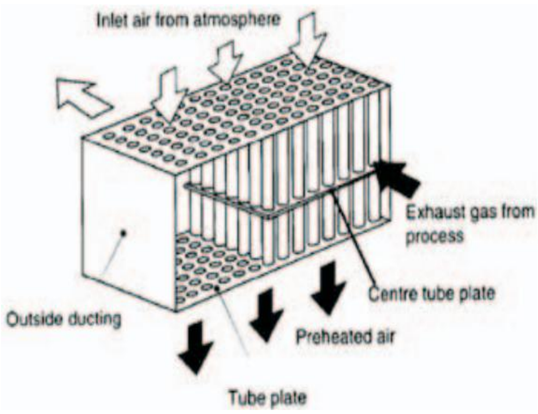


Fig. 1 WHR using Recuperator

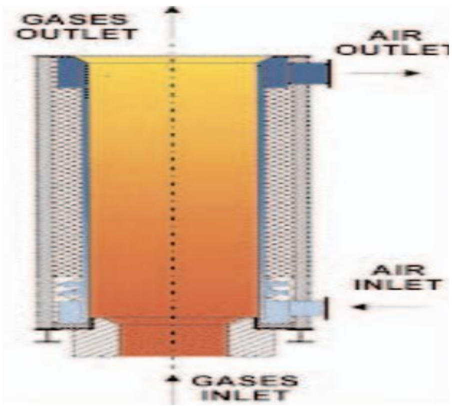


Fig. 2 Metallic Radiation Recuperator

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

A second common configuration for recuperators is called the tube type or convective recuperator.

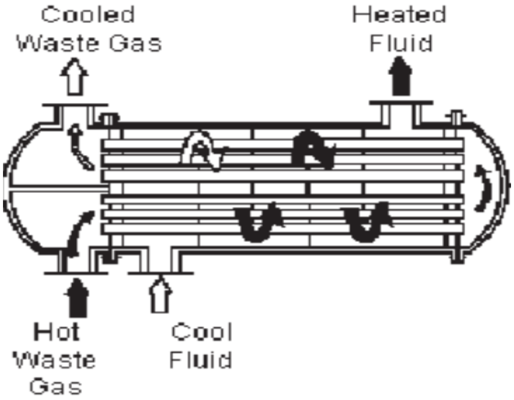


Fig. 3 Convective Recuperator

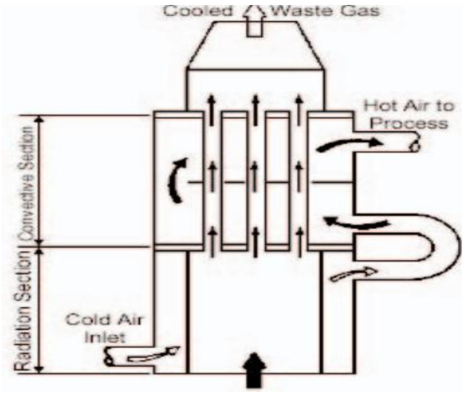
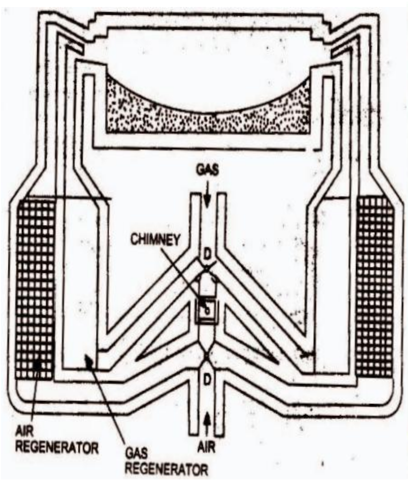


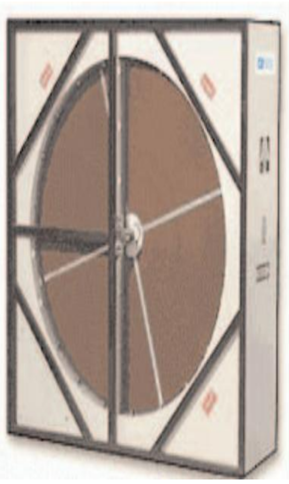
Fig. 4 Convective Radiative Recuperator

As seen in the fig. 3, the hotgases are carried through a number of parallelsmall diameter tubes, while the incoming air to beheated enters a shell surrounding the tubes andpasses over the hot tubes one or more times in adirection normal to their axes.

Radiation/Convective Hybrid Recuperator- For maximum effectiveness of heat transfer, combinations of radiation and convective designs areused, with the high-temperature radiation recuperator being first followed by convection type.These are more expensive than simple metallic radiation recuperators, but are less bulky. A Convective/ radiative Hybrid recuperator is shown in fig. 4

Regenerator-The Regeneration which is preferable forlarge capacities has been very widely used inglass and steel melting furnaces. Importantrelations exist between the size of the regenerator, time betweenreversals, thickness ofbrick, conductivity of brick and heat storageratio of the brick.In a regenerator, the time between thereversals is an important aspect. Longperiods would mean higher thermalstorageand hence higher cost. Also long periods ofreversal result in lower average temperatureof preheat and consequently reduce fueleconomy.





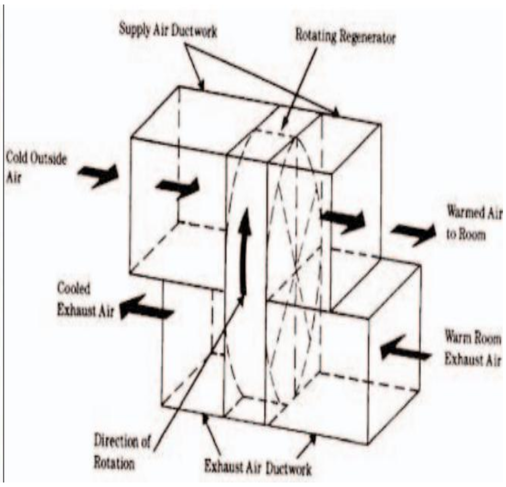


Fig. 5 Regenerator

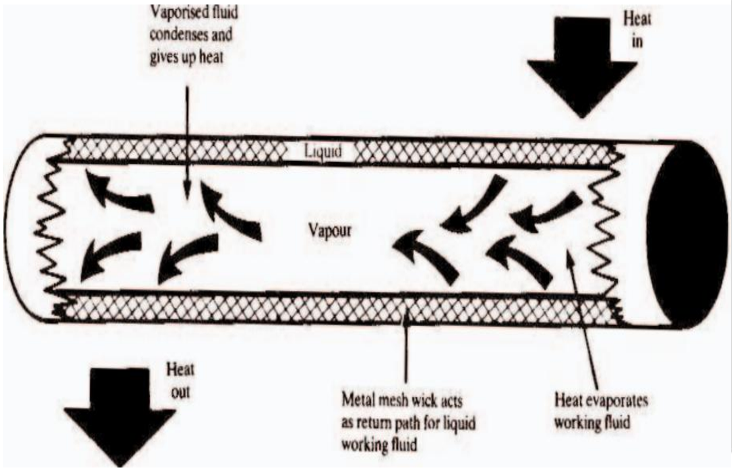
Fig. 6 Heat Wheel

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

(Fig. 5). Accumulation of dust and slagging onthe surfaces reduce efficiency of the heattransfer as the furnace becomes old.Heat losses from the walls of the regenerator and air in leaks during the gas period and outleaks during air period also reduces the heat transfer.

Heat Wheels-It is finding increasing applications in low to medium temperature waste heat recovery systems. Fig. 6 is a sketch illustrating the application of a heat wheelIts main area of application is where heat exchange between large masses of air havingsmall temperature differences is required. Heating and ventilation systems and recovery of heatfrom dryer exhaust air are typical applications. [3]

Heat Pipe - A heat pipe can transfer up to 100 times more thermal energy than copper, the best known conductor. In other words, heat pipe is a thermal energy absorbing and transferring system and haveno moving parts and hence require minimum maintenance.Heat pipe is shown in fig. 7 [7]



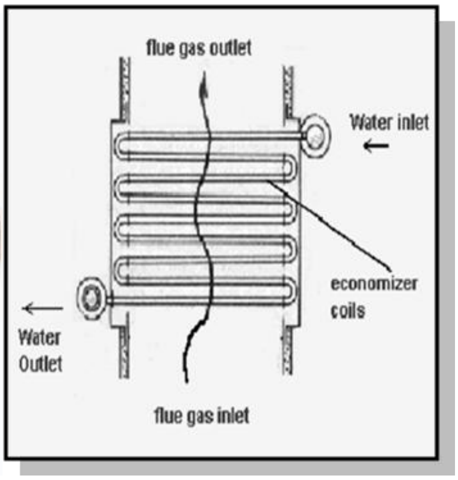


Figure 7 Heat Pipe **Fig. 8 Economiser**

Typical Application

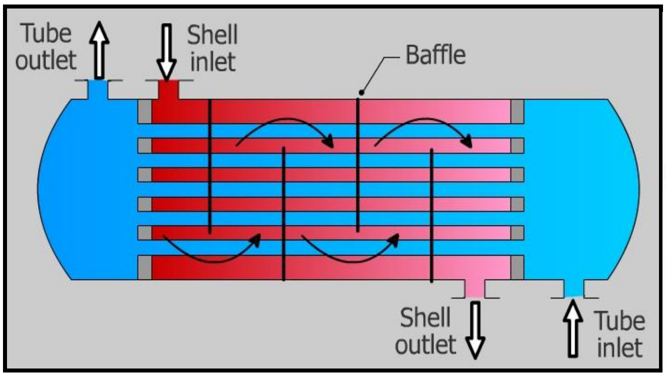
a. Process to Space Heating: The heat pipe heat exchanger transfers the thermal energyfrom process exhaust for building heating. The preheated air can be blended if required

b. Process to Process: The heat pipe heat exchangers recover waste thermal energy fromthe process exhaust and transfer this energy to the incoming process air. The incomingair thus become warm and can be used for the same process/other processes and reducesprocess energy consumption.

c. HVAC Applications:Cooling: Heat pipe heat exchangers precools the building make up air in summer andthus reduces the total tons of refrigeration, apart from the operational saving of the cooling system.

Economiser -In case of boiler system, economizer can beprovided to utilize the flue gas heat for preheating the boiler feed water. On the otherhand, in an air pre-heater, the waste heat isused to heat combustion air. In both thecases, there is a corresponding reduction inthe fuel requirements of the boiler.Economizer is shown infig.8.

Shell and Tube Heat Exchanger- When the medium containing waste heat is a liquid or a vapour which heats another liquid, thenthe shell and tube heat exchanger must be used since both paths must be sealed to contain thepressures of their respective fluids. A shell and tube heat exchanger is illustrated in fig. 9.



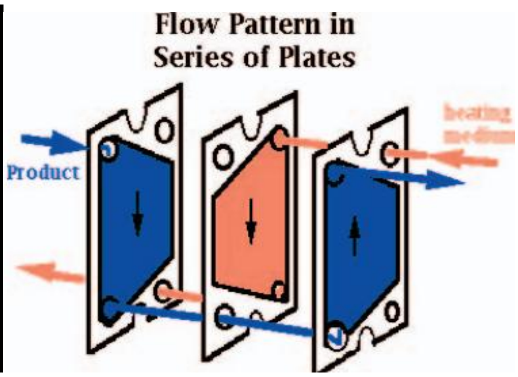
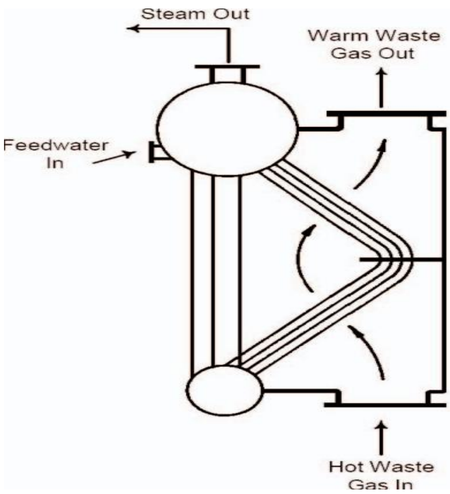


Fig. 9 Shell & Tube Heat Exchanger **Fig. 10 Plate Heat Exchanger**

Typical applications of shell and tube heat exchangers include heating liquids with the heatcontained by condensates fromrefrigeration and air-conditioning systems; condensate fromprocess steam; coolants from furnace doors, grates, and pipe supports; coolants from engines,air compressors, bearings, and lubricants; and the condensates from distillation processes.

Plate heat exchanger- The cost of heat exchange surfaces is amajor cost factor when the temperature differences are not large. A plate heat exchanger is shown in fig10.[4] Typical industrial applications arePasteurisation section in milk packaging plant,Evaporation plants in food industry.

Waste Heat Boilers -Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases from gasturbines, incinerators, etc., pass over a number of parallel tubes containing water. Waste heat boilers are built in capacities from 25 m3 almost30,000 m^3 / min. of exhaust gas.Typical applications of waste heat boilers are to recover energy from the exhausts of gas turbines, reciprocating engines, incinerators, and furnaces.



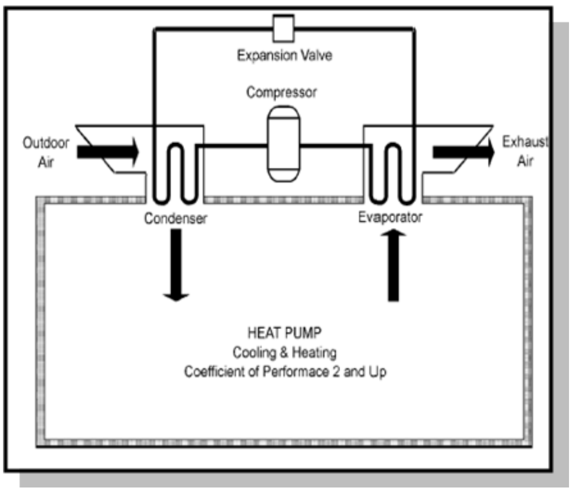


Fig. 11 Two-Pass Water Tube WHR Boiler **Fig. 12 Heat Pump Arrangement**

Heat Pumps-In the various commercial options previously discussed, we find waste heat being transferredfrom a hot fluid to a fluid at a lower temperature. Heat must flow spontaneously "downhill",that is from a system at high temperature to one at a lower temperature. When energy is repeatedly transferred or transformed, it

International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 12, December 2016
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

becomes less and less available for use. Eventually thatenergy has such low intensity (resides in a medium at such low temperature) that it is no longeravailable at all to perform a useful function. Heat pump applications are most promising when both the heating and cooling capabilitiescan be used in combination. One such example of this is a plastics factory where chilled waterfrom a heat is used to cool injection-moulding machines whilst the heat output from the heatpump is used to provide factory or office heating. Other examples of heat pump installationinclude product drying, maintaining dry atmosphere for storage and drying compressed air.

Thermo-compressor-In many cases, very low pressure steam are reused as water after condensation for lack of any betteroption of reuse. In many cases it becomes feasible to compress this low pressure steam by very highpressure steam and reuse it as a medium pressure steam. The major energy in steam, is in its latentheat value and thus thermo-compressing would give a large improvement in waste heat recovery. Thermo-compressor is shown in fig. 13

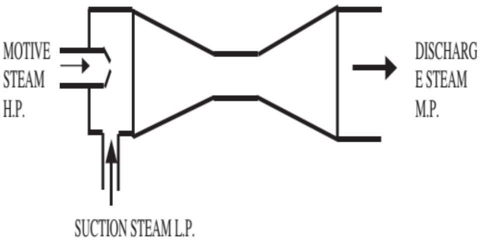


Fig.13 Thermo-compressor

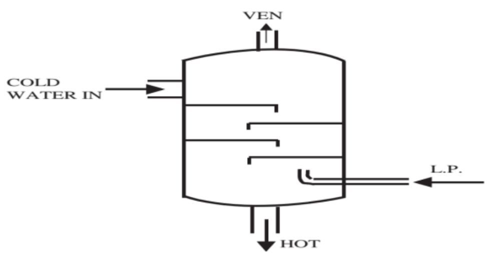


Fig. 14 Direct Contact Condenser

It is typically used in evaporators where the boiling steam is recompressed and used as heatingsteam.

Direct Contact Heat Exchanger-Low pressure steam may also be used to preheat the feed water or some other fluid where miscibility is acceptable. This principle is used in Direct Contact Heat Exchanger and finds wideuse in a steam generating station. Direct contact heat exchanger is shown in fig.14. Typical application is in the deaerator of a steam generation station.

IV. CASE EXAMPLES

1. A rotary heat regenerator was installed on a two colour printing press to recover some of the heat, which had been previously dissipated to the atmosphere, and used for drying stage of the process. The outlet exhaust temperature before heat recovery was often in excess of 100°C. After heat recovery the temperature was 35°C. Percentage heat recovery was 55% and payback on the investment was estimated to be about 18 months. Cross contamination of the fresh air from the solvent in the exhaust gases was at a very acceptable level.

2. A ceramic firm installed a heat wheel on the preheating zone of a tunnel kiln where 7500 m^3/hour of hot gas at 300°C was being rejected to the atmosphere. The result was that the flue gas temperature was reduced to 150°C and the fresh air drawn from the top of the kiln was preheated to 155°C. The burner previously used for providing the preheated air was no longer required. The capital cost of the equipment was recovered in less than 12 months. [3]

3. Savings in Hospital Cooling Systems

Volume 140- m^3/min Exhaust

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Recovered heat- 28225 kCal/hr

Plant capacity reduction- 9.33 TR

Electricity cost (operation)- Rs. 268/Million kCal (based on 0.8 kW/TR)

Plant capacity reduction cost (Capital)- Rs.12,000/TR

Capital cost savings- Rs. 1,12,000/-

Payback period- 16570 hours

4. Gases leaving a carbon black plant rich in carbon monoxide which are vented to theatmosphere.

Equipment Suggested	CO incinerator along with **waste heat boiler**& steam turbine
Estimated equipment cost	Rs.350 Lakhs
New boiler efficiency	80%
Savings	Rs.160 Lakhs /annum
Indirect benefits	Reduction in pollution levels

5. Exhaust steam from evaporator in a fruit juice concentrator plant was condensed in a precondenser operation on cooling water upstream of a steam jet vacuum ejector

Equipment Suggested	Alt-1 Thermo-compressor
	Alt-2 shell & tube exchanger
Cost of thermo-compressor	Rs.1.5 Lakhs
Savings of jacket steam due to recompression of vapour	Rs.5.0 Lakhs per annum
Cost of shell &tube exchanger to preheat feed water	Rs.75,000/-
Savings in fuel cost	Rs.4.5 Lakhs per annum

V. RESULTS

The rising cost of energy, combined with increasingly stringent legislation to reduce greenhouse gas emissions is driving process industries towards increasing energyefficiency. Significant gains can bemade in this sector by recovering low-grade waste heat as up to (4% of total energyuse) of the Indian process industries' energyconsumption is lost as recoverablewaste heat. Substantial recovery of this wouldhave economic benefits and environmentalbenefits of 100s of thousands of tonnes of carbon dioxide equivalent per year. A similar situation is envisaged in otherindustrialised countries.

This work describes the development of a knowledge-based system for the selection and preliminary design of equipment for waste heat recovery in the process industries. The system processescommonly available plant data to select the most appropriate technology for waste heat recovery froma range of programmed options. Case-study testing shows that the system can successfully select anddesign viable solutions for waste heat recovery from a range of options, producing designs which areeconomically, environmentally and technically feasible.

VI. CONCLUSIONS

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose. The

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

essential quality of heat is not the amount but rather its "value". The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by combining above devices at certain point in process industry.

REFERENCES

1.Fuel Economy in furnaces and Waste heat recovery- PCRA

2. Heat Recovery Systems by *D.A. Reay*, E & F.N.Span, London, 1979.

3. F. Fathieh, R.W. Besant, R.W. Evitts, C.J. Simonson; Determination of air-to-air heat wheel sensible effectiveness using temperature step change data; International Journal of Heat and Mass Transfer 87 (2015) 312-326.

4. Tongcai Wang, Weiling Luan, Wei Wang, Shan-Tung Tu; Waste heat recovery through plate heat exchanger based thermoelectricgenerator system; Applied Energy 136 (2014) 860-865.

5. Sarah Brückner, Selina Liu, LaiaMiró, Michael Radspieler, Luisa F. Cabeza,Eberhard Lävemann; Industrial waste heat recovery technologies: An economic analysis ofheat transformation technologies; Applied Energy 151 (2015) 157-167.

6. GbemiOluleye, Megan Jobson, Robin Smith, Simon J. Perry; Evaluating potential of process sites for waste heat recovery; Applied Energy 161 (2016) 627-646.

7. Hongting Ma, Lihui Yin, Xia openg Shen, Wenqian Lu, Yuexia Sun, Yufeng Zhang, Na Deng; Experimental study on heat pipe assisted heat exchanger usedfor industrial waste heat recovery; Applied Energy 169 (2016) 177-186.

8. A.B. Etemoglu; Thermodynamic investigation of low-temperature industrial waste-heat recovery in combined heat and power generation systems; International Communications in Heat and Mass Transfer 42 (2013) 82-88.