© 2017 IJSRST | Volume 3 | Issue 1 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Scienceand Technology

Waste Heat Recovery Systems for Refrigeration-A Review

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ABSTRACT

During various industrial processes, as much as 20 to 50% of the energy consumed is ultimately lost via waste heat contained in streams of hot exhaust gases, exhaust steam and hot liquids, as well as through heat transfer from hot equipment surfaces. Captured and reused waste heat is a valuable approach to improve overall energy efficiency by optimizing for costly purchased fuels or electricity and for the protection of global environment from pollution and rate of global warming. The applications of waste heat energy include generating electricity, preheating combustion air, space heating, refrigeration, etc. This review paper studies how refrigeration can be achieved quantitatively as well as qualitatively in different domains by using various waste heat recovery technologies from key industrial waste heat sources. This paper also studies the huge annual energy savings and environmental benefits that can be resulted by using these waste heat recovery technologies for refrigeration.

Keywords: Waste Heat, Waste Heat Recovery Technologies, Refrigeration, Energy Savings.

I. INTRODUCTION

Industrial waste heat refers to energy that is generated in industrial processes without being put to practical use. The sources of waste heat include streams of hot exhaust gases, exhaust steam and hot liquids, as well as through heat conduction, convection, and radiation from hot equipment surfaces. The various studies have estimated that as much as 20 to 50% of industrial energy consumption is ultimately discharged as waste heat. While some waste heat losses from industrial processes are inevitable, these losses can be reduced by improving equipment efficiency or installing waste heat recovery technologies. Waste heat recovery entails capturing and reusing the waste heat in industrial processes for various applications which include generating electricity, preheating combustion air, space heating, refrigeration and air conditioning, etc.Captured and reused waste heat is a valuable approach to improve overall energy efficiency by optimizing for costly purchased fuels or electricity and for the protection of global environment from pollution and rate of global warming.

The essential components (Figure 1) required for waste heat recovery are: 1) an accessible source of waste heat, 2) a recovery technology, and 3) a use for the recovered energy.

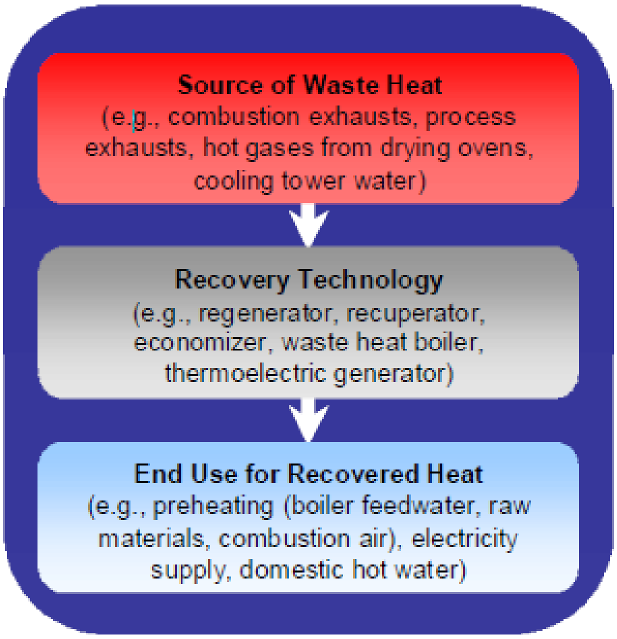

Figure 1. Three essential components required for waste heat recovery

This review paper first studies waste heat recovery feasibility and common waste heat recovery technologies and then mainly focuses review on waste heat recovery technologies for refrigeration purpose with the key advantages throughout the paper.

1. Factors Affecting Waste Heat Recovery Feasibility

Evaluating the feasibility of waste heat recovery requires characterizing the waste heat source and the stream to which the heat will be transferred. Important waste stream parameters that must be determined include:

- Heat Quantity,
- Heat Temperature/Quality,
- Composition,
- Minimum Allowed Temperature, And
- Operating Schedules, Availability, And Other Logistics.

These parameters allow for analysis of the quality and quantity of the stream and also provide insight into possible materials/design limitations. For example, corrosion of heat transfer media is of considerable concern in waste heat recovery, even when the quality and quantity of the stream is acceptable. The following provide an overview of important concepts that determine waste heat recovery feasibility [1].

1.1 Heat Quantity

The quantity, or heat content, is a measure of how much energy is contained in a waste heat stream. The quantity of waste heat contained in a waste stream is a function of both the temperature and the mass flow rate of the stream:

$$\mathbf{E = m\ h(t)} \quad \text{Equation (1)}$$

where E is the waste heat loss ; m is the waste stream mass flow rate; and h(t) is the waste stream specific enthalpy as a function of temperature.

1.2 Waste Heat Temperature/Quality

In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the heat sink temperature. Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heat's utility or "quality". The source and sink temperature difference influences a) the rate at which heat is transferred per unit surface area of heat exchanger, and b) the maximum theoretical efficiency of converting thermal from the heat source to another form of energy (i.e., mechanical or electrical). Finally, the temperature range has important ramifications for the selection of materials in heat exchanger designs. Waste heat recovery opportunities are categorized in this report by dividing temperature ranges into low, medium, and high quality of waste heatsources as follows:

High:	1,200ºF [649ºC]	and higher
Medium:	450ºF [232ºC]	to 1,200ºF [650ºC]
Low:	450ºF [232ºC]	and lower.

1.3 Waste Stream Composition

Although chemical compositions do not directly influence the quality or quantity of the available heat (unless it has some fuel value), the composition of the stream affects the recovery process and material selection. The composition and phase of waste heat streams will determine factors such as thermal conductivity and heat capacity, which will impact heat exchanger effectiveness. Meanwhile, the process specific chemical makeup will have an important impact on heat exchanger designs, material constraints, and costs. Heat transfer rates in heat exchangers are dependent on the composition and phase of waste heat streams, as well as influenced by the deposition of any fouling substances on the heat exchanger. Denser fluids have higher heat transfer coefficients, which enables higher heat transfer rates per unit area for a given temperature difference (Table 1).

Table1. General Range of Heat Transfer Coefficients for Sensible Heat Transfer in Tubular Exchangers

Fluid Conditions	Heat Transfer Coefficient (W/(m^2 • °K)

Water, liquid	5×10^3 to 1×10^4
Light organics, liquid	1.5×10^3 to 2×10^3
Gas (P = 1,000 kPa)	2.5×10^2 to 4×10^2
Gas (P = 100200 kPa)	8×10 to 1.2×10^2

1.4 Minimum Allowable Temperature

The minimum allowable temperature for waste streams is often closely connected with material corrosion problems. Depending on the fuel used, combustion related flue gases contain varying concentrations of carbon dioxide, water vapor, NO_X, SO_X, unoxidized organics, and minerals. If exhaust gases are cooled below the dew point temperature, the water vapor in the gas will condense and deposit corrosive substances on the heat exchanger surface. Heat exchangers designed from low cost materials will quickly fail due to chemical attack. The minimum temperature for preventing corrosion depends on the composition of the fuel.

The most common method for preventing chemical corrosion is designing heat exchangers with exhaust temperatures well above the dew point temperature.

1.5 Economies of Scale, Accessibility, and Other Factors

Several additional factors can determine whether heat recovery is feasible in a given application. For example, small scale operations are less likely to install heat recovery, since sufficient capital may not be available, and because payback periods may be longer. Operating schedules can also be a concern. If a waste heat source is only available for a limited time every day, the heat exchanger may be exposed to both high and low temperatures. In this case, one must ensure that the heat exchange material does not fatigue due to thermal cycling. Additionally, it is important that the schedule for the heat source match the schedule for the heat load. Another concern is the ease of access to the waste heat source. In some cases, the physical constraints created by equipment arrangements prevent easy access to the heat source, or prevent the installation of any additional equipment for recovering the heat.

2. Waste Heat Recovery Technologies

Typical technologies used for waste heat recovery are as follows [1] [2] [3]:

2.1 Recuperators

In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic 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 Figure 2. The various types of recuperator available are Metallic Radiation Recuperator, Radiation/Convective Hybrid Recuperator and Ceramic Recuperator.

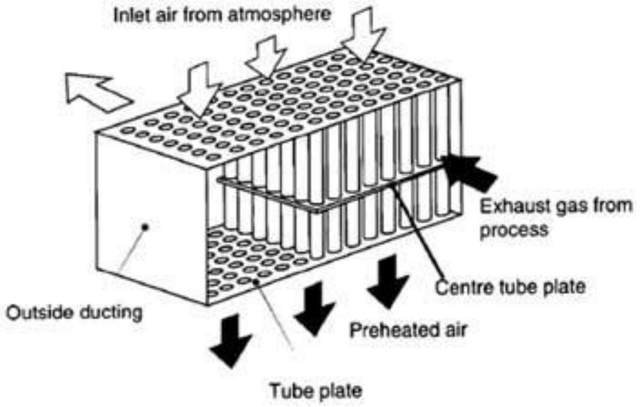

Figure 2. Waste Heat Recovery using Recuperator

2.2 Regenerator

The Regeneration which is preferable for large capacities has been very widely used in glass and steel melting furnaces.

2.2.1 Furnace Regenerator

Regenerative furnaces consist of two brick “checkerwork” chambers through which hot and cold airflow alternately (Figure 3). As combustion exhausts pass through one chamber, the bricks absorb heat from the combustion gas and increase in temperature. The flow of air is then adjusted so that the incoming combustion air passes through the hot checkerwork, which transfers heat to the combustion air entering the furnace. Important relations exist between the size of the regenerator, time between reversals, thickness of brick, conductivity of brick and heat storage ratio of the brick.

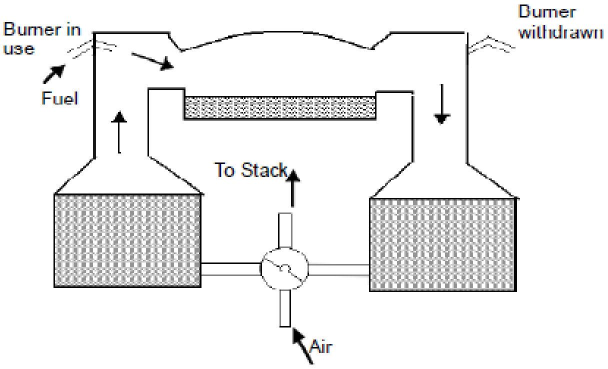

Figure 3. Regenerative Furnace Diagram

2.2.2 Rotary Regenerator/Heat Wheel

Rotary regenerators operate similar to fixed regenerators in that heat transfer is facilitated by storing heat in a porous media, and by alternating the flow of hot and cold gases through the regenerator. Rotary regenerators, sometimes referred to as air preheaters and heat wheels, use a rotating porous disc placed across two parallel ducts, one containing the hot waste gas, the other containing cold gas (Figure 4).

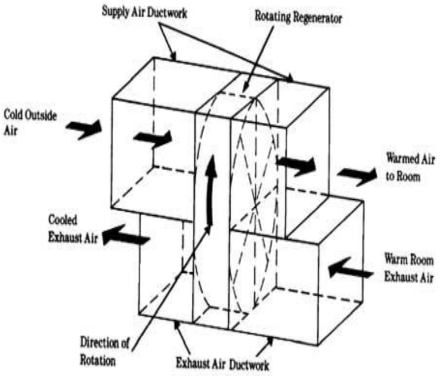

Figure 4. Heat Wheel

3.3 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 have no moving parts and hence require minimum maintenance. The Heat Pipe comprises of three elements – a sealed container, a capillary wick structure and a working fluid. The capillary wick structure is integrally fabricated into the interior surface of the container tube and sealed under vacuum. Thermal energy applied to the external surface of the heat pipe is in equilibrium with its own vapour as the container tube is sealed under vacuum. This thermal energy causes the working fluid near the surface to evaporate instantaneously. Vapour thus formed absorbs the latent heat of vapourisation and this part of the heat pipe becomes an evaporator region. The vapour then travels to the other end the pipe where the thermal energy is removed causing the vapour to condense into liquid again, thereby giving upthe latent heat of the condensation. This part of the heat pipe works as the condenser region. The condensed liquid then flows back to the evaporated region. A figure of Heat pipe is shown in Fig. 5.

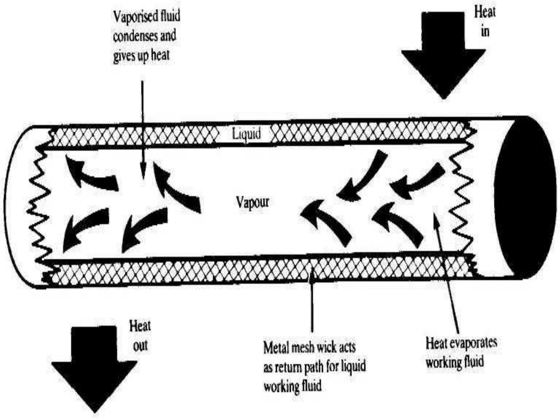

Figure 5. Heat Pipe

3.4 Economiser

In case of boiler system, economizer can be provided to utilize the flue gas heat for pre-heating the boiler feed water. On the other hand, in an air pre-heater, the waste heat is used to heat combustion air. In both the cases, there is a corresponding reduction in the fuel requirements of the boiler. A economizer is shown in Figure 6.

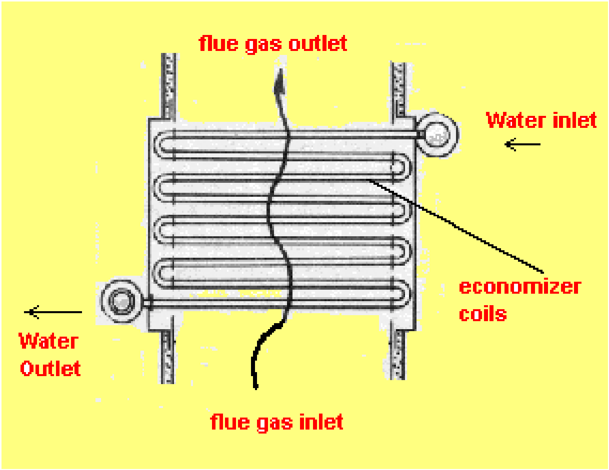

Figure 6. Economiser

2.5 Shell and Tube Heat Exchanger

When the medium containing waste heat is a liquid or a vapor which heats another liquid, then the shell and tube heat exchanger must be used since both paths must be sealed to contain the pressures of their respective fluids. The shell contains the tube bundle, and usually internal baffles, to direct the fluid in the shell over the tubes in multiple passes. The higher-pressure fluid is circulated in the tubes while the lower pressure fluid flows through the shell. When a vapor in the shell contains the waste heat, it usually condenses, giving up its latent heat to the liquid in tubes being heated. A shell and tube heat exchanger is illustrated in Figure 7.

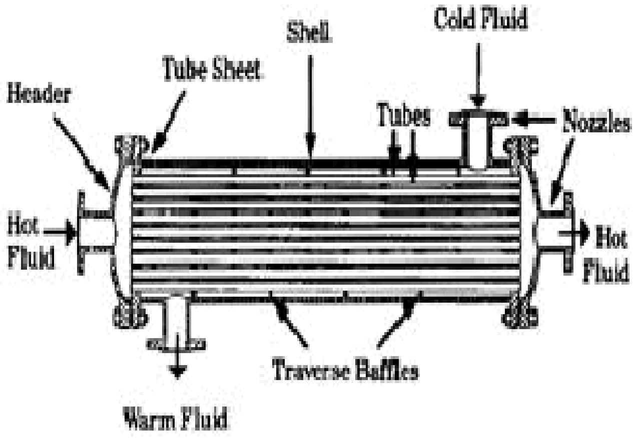

Figure 7. Shell & Tube Heat Exchanger

2.6 Heat Pumps

The heat pump was developed as a space heating system where low temperature energy from the ambient air, water, or earth is raised to heating system temperatures by doing compression work with an electric motor-driven compressor. The majority of heat pumps work on the principle of the vapour compression cycle. In the heat pump, in the evaporator the heat is extracted from the heat source to boil the circulating substance. The circulating substance is compressed by the compressor, raising its pressure and temperature. The low temperature vapor is compressed by a compressor, which requires external work. The work done on the vapor raises its pressure and temperature to a level where its energy becomes available for use. The heat is delivered to the condenser. The pressure of the circulating substance (working fluid) is reduced back to the evaporator condition in the throttling valve, where the cycle repeats. The arrangement of a heat pump is shown in Figure 8.

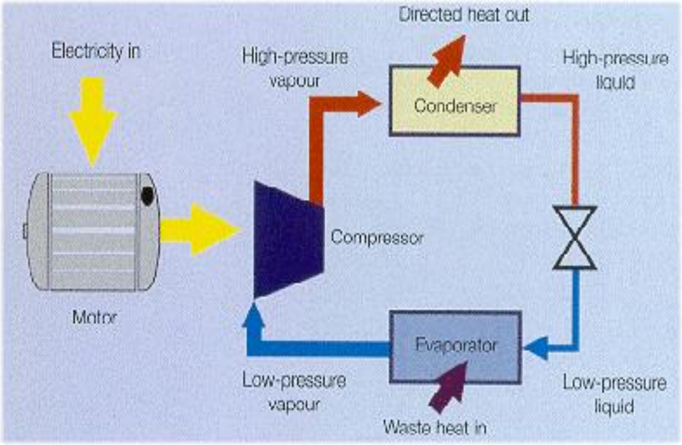

Figure 8. Heat Pump

Review on Waste Heat Recovery for Refrigeration Purpose

The primary purpose of refrigeration is lowering the temperature of the enclosed space or substance and then maintaining that lower temperature as compare to surroundings. This paper now reviews how refrigeration can be achieved in different domains by using various waste heat recovery technologies.

3.1 Combined Refrigeration Cycle for Thermal Power Plant Using Low Grade Waste Steam

Satish Maury and Dharmendra Patel [4] presented and studied how in a thermal power plant, a vapour absorption and vapour compression can be used together as one complete working refrigeration plant by using waste heat. The figure shows the arrangement of various components used in combined vapour absorption/compression refrigeration system.

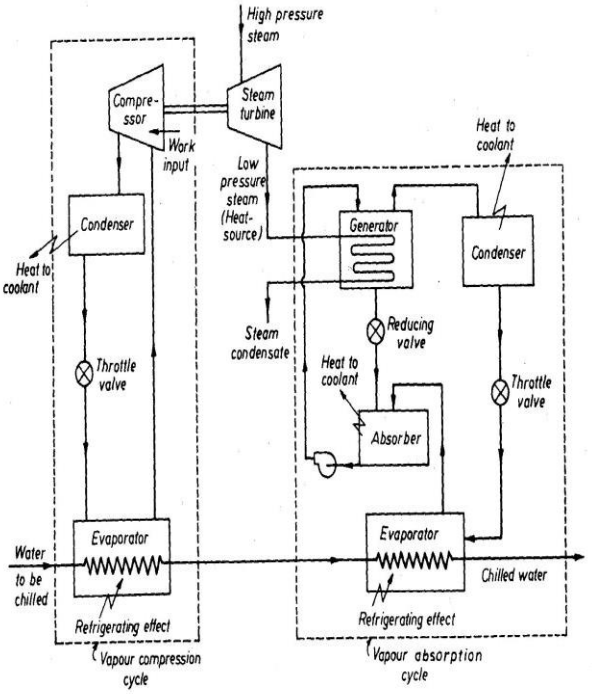

Fig.9: Combined vapour absorption/compression system

The first part of cycle consists of a vapour compression cycle powered by the high pressure steam turbine (this steam is bled from the main power generating high pressure steam turbine). Rest of the part is working in same manner as normal compression cycle. In vapour compression refrigeration cycle compressor is the main part which required work input to operate the whole system.

In a Rankine cycle, after expansion of steam in turbine, a low pressure steam is obtained. This low pressure steam operates the vapour absorption system (shown in fig.9). Ammonia vapour at high pressure transfers heat to neighborhood in the condenser. Liquid ammonia from the condenser is passed through an expansion valve to reach the evaporator pressure. Heat is transferred from the low temperature heat source to convert liquid ammonia to vapour state. Ammonia vapour is absorbed by a weak solution of water and ammonia to form a concentrated solution of ammonia-water at the bottom of absorber. This concentrated solution is passed to the generator for the production of ammonia vapour while the lean solution from the generator is passed back to the absorber unit. Low grade heat is used in the generator for the production of ammonia vapour. Lean ammonia solution from the generator exchanges heat with the high concentration ammonia solution from the absorber. The given low pressure steam is sufficient to operate the generator of the absorption cycle. After the generator the steam is supplied to the condenser and passed towards the power generation cycle.

The waste heat obtained from various sections of the plant could be used to operate the small scale refrigeration systems. By using such refrigeration system there is no need to supply any external power or heat to operate it and hence increase the COP of the refrigeration system. Drinking water chilling and air conditioning are the advantageous applications of such combined refrigeration system.

3.2 A Cooling System for an Automobile Based on Vapour Absorption Refrigeration Cycle Using Waste Heat of an Engine

Satish K. Maurya, SaurabhAwasthi, Suhail A. Siddiqui[5]have studied and analyseda cooling system for an automobile based on ammonia vapour absorption refrigeration cycle using waste heat of an engine. The air conditioning system of most of the cars mainly uses “Vapour Compression Refrigerant System” (VCRS) which absorbs and removes heat from the interior of the car that is the space to be cooled and rejects the heat to atmosphere. In vapour compression refrigerant system, the system utilizes power from engine shaft as the input power to drive the compressor of the refrigeration system, hence the engine has to produce extra work to run the compressor of the refrigerating system utilizing extra amount of fuel. This loss of power of the vehicle for refrigeration can be avoided by utilizing another refrigeration system i.e. a “Vapour Absorption Refrigerant System” (VAS). These machines required low grade energy for operation. Hence in such types of system, a physicochemical process replaces the mechanical process of the Vapour Compression Refrigerant System by using energy in the form of heat rather than mechanical work. This heat obtained from the exhaust of high power internal combustion engines and the rest operation of Ammonia VAS is similar as described in previous section. The arrangement is shown in fig. 10.

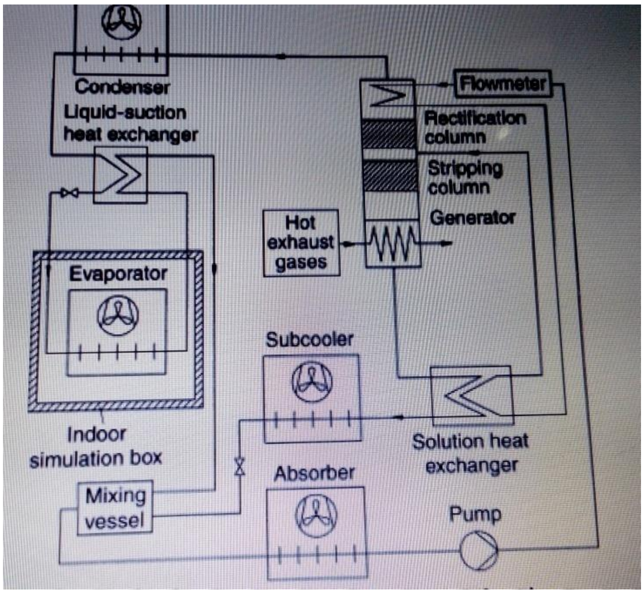

Fig.10: The essential components of the air-cooled absorption system.

In Vapour absorption refrigeration system, generator portion is designed for utilizing exhaust gas from internal combustion engine. Type of engine and also details of engine parameters are given below.

1	Engine Make	Kirloskar
2	Engine Type	Single Cylinder
3	Power	3.7 kW
4	Speed	1500 rpm
5	Bore dia	80 mm
6	Stroke Length	110 mm
7	Room Temp.	29 ℃
8	Exhaust Gas Temp. Range	125℃ to 260℃

This system uses engine heat as source of energy and hence enhances the efficiency of engine. The system has moving parts only in the pump, which is a small element in the system and hence operation becomes smooth and also wearing and tearing is reduced. The system works at low evaporator pressures without affecting the COP of the system and has low running cost. This system is eco-friendly as it involves the use of Ammonia as a refrigerant which is a natural gas and is not responsible for OZONE layer Depletion.

3.3 Flue gas low temperature heat recovery system for refrigeration and air-conditioning

NirmalSajan, Ruben Philip, Vinayak Suresh, Vishnu M and Vinay Mathew John, Saintgits College of Engineering, Kerala[6]have designed and analysed flue gas low temperature waste heat recovery system for refrigeration and air-conditioning.In their work, the waste heat of flue gas in a 350 MW thermal power plant is utilized in vapor absorption machine (VAM) air conditioning plant by using gas to liquid multi-pass cross flow heat exchanger that is to be placed in the space between boiler and chimney. The extracted energy from the flue gas has produced a refrigerating capacity of 70 TR approximately and thus can share or replace refrigeration load of thermal power plant with the normally used vapour compression machine (VCM). This work also aims in replacing Freon-12 refrigerant which causes ozone depletion and to reduce the temperature of exhaust gas emitted to the atmosphere which causes global warming.

Due to the corrosive nature of flue gas, heat recovery is confined up to the acid dew point temperature of the flue gas. Suitable software is used to find out the detailed and economic design parameters of gas to liquid multi-pass cross flow heat exchanger.

3.3.1 Analytical set up and Working process of the system

The working process is intended for maximum heat recovery from the flue gas which is at a temperature of 125^{o}C. At this very low temperature the thermal and structural effects on the heat exchanger to be designed can be neglected. The working fluid selected is water because of its relative abundance and its non-toxic nature along with its high heat capacity. The process begins when the heat exchanger installed in the space between the boiler and the chimney taps the heat from the flue gas. The flue gas after rejecting heat to the heat exchanger passes through the chimney. A pump of predetermined mass flow rate is used to transfer water from a reservoir to the heat exchanger which heats up to the desired temperature through a cascade process involving multi-pass tubes of the heat exchanger. The heated water is then pushed forward by the pressure existing in the system to the generator part of the VAM which have a capacity of 70 TR and a COP of 0.7. The water coming out of VAM which is still at a considerable temperature is brought to ambient temperature by passing it through the cooling tower which is already present at the plant. The cooled water is then returned to the reservoir from where it is again pumped by the water pump. A make- up feed water arrangement is also provided with the reservoir to compensate for any losses.

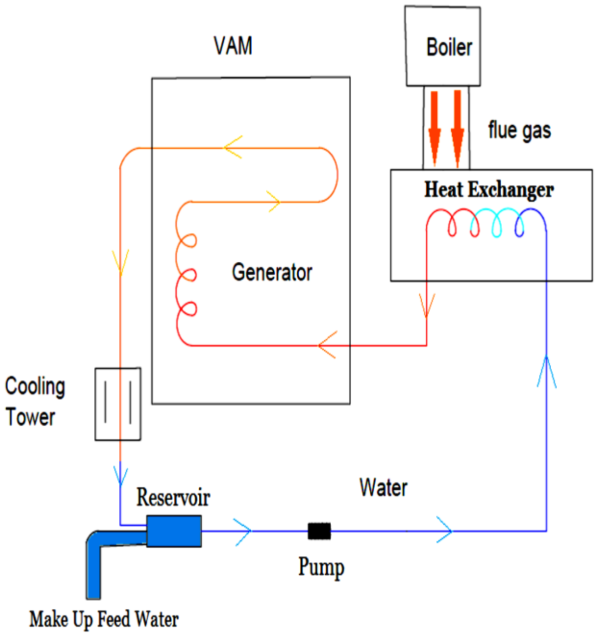

Figure 11. Detailed sketch of setup

3.3.2 Design data

By using thermal power plant data sheet and the required heat exchanger calculations, the dimensions of the finally selected heat exchanger are found as 0.106m × 2.4m × 3.4m. The number of pipes required for the heat exchanger is found to be 12 using iteration method. The material used for fabrication of heat exchanger is of aluminum. Since this heat recovery is in the very low temperature and also aluminum is less denser, it is the most suitable choice.

3.3.3 Analysis

The heat exchanger analysis was carried out using ANSYS FLUENT software. Although the design involves a multi-pass heat exchanger consisting of twelve pipes, the analysis was carried out only on the first and the last pipe of the heat exchanger. This is because the properties of flue gas flowing through the space between boiler and chimney and the water flowing through the pipe respectively are same for each pipe. The dimensions of the heat exchanger is scaled down to one – tenth of its original dimensions due to considerable difficulty faced during the analysis of 1:1 model of the heat exchanger. But the resulting error will be only one percent. A rectangular control volume of cross sectional area of 30 cm^2 is also considered which encloses the pipe. The flow analysis of both the cold fluid and the hot fluid was carried out in the control volume considered.

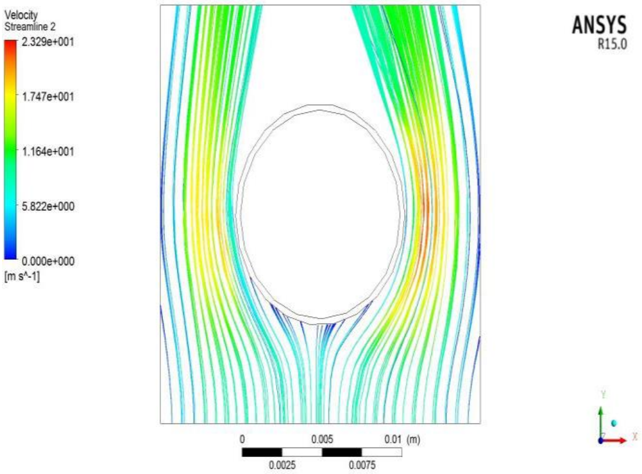

Figure 12. Velocity Streamline of Flue Gas

Fig. 12 shows the **velocity streamlines analysis** of flue gas. From the figure, it can be understood that the velocity of flue gas increases when it approaches the pipe and decreases when it passes the pipe. It is due to the reduction in area that occurs when the flue gas approaches the pipe and the subsequent reduction in pressure. As the flow area increases the velocity of the flue gas decreases correspondingly. It can also be inferred that the velocity of the flue gas directly below the pipe is almost zero. This may be due to the near stagnation condition that arises at that region.

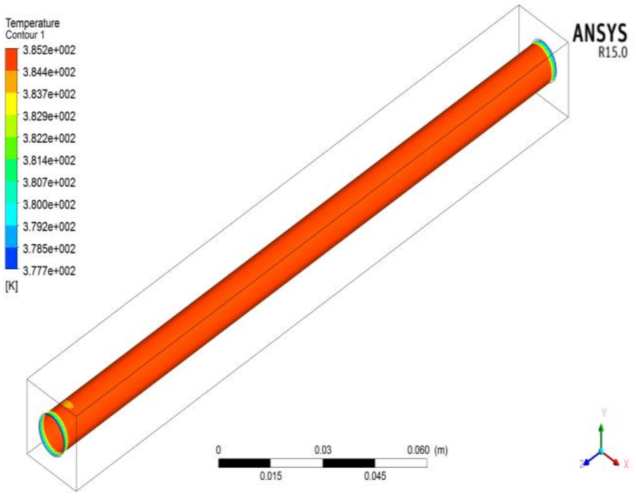

Figure 13. Temperature contour of the inner wall of pipe 12

Temperature analysis is carried out by considering only the inner wall of the pipes 1 and 12. Other pipes are not considered. This is because all the pipes exhibit same behavior. Fig. 13 shows the **temperature analysis** of inner wall of pipe 12. From this pipe we can see that temperature is same at all regions of the wall. Water enters the last pipe after passing through all the 11 pipes and the temperature of water goes on increasing as it pass through each pipe since it is a multi-pass heat exchanger. High temperature water at about 95℃ enters into the last pipe. Since temperature of the water is very high, heat from the walls is distributed to the walls of the pipe. Also wall is heated due to temperature of flue gas. This may be the reason that inner wall of pipe has higher temperature at all its regions.

Table 2.Average outlet temperatures of different pipes

Pipe No.	Inlet Temperature (K)	Outlet Temperature (K)
1	300	309.6
2	309.6	320.3
3	320.3	325.1
4	325.1	333.6
5	333.6	341.4
6	341.4	347.7
7	347.7	353.6
8	353.6	359.1
9	359.1	363.6
10	363.6	368
11	368	371.5
12	371.5	374.1

The extracted energy from the flue gas has produced a refrigerating capacity of 70 TR by the heated water from the heat exchanger pushed forward to the generator part of the VAM which have a COP of 0.7.

Power required for operating VCM =78.2985 KW and power required for operating VAM = 2% of VCM =1.566 KW.

Total Power Saved = 78.2985 – 1.566 = 76.732 KW
Energy saved if air-conditioner works 12 hours per day = 76.732 × 12 = 920.784 KWhr = 920.784 Units/day.

3.4 Study and Design of Waste Heat Recovery using Organic Rankine Cycle

Seyed Saied Homami, Ahmad Khoshgard, Maryam Momenifar,HamedNematiSayad and HamidrezaHeidarimoghadam from universities of Iran [7]have studied and designed waste heat recovery system using Organic Rankine cycle. In refineries and petrochemical complexes, waste Low Pressure (LP) steam which is usually output of the steam turbines discharges into the atmosphere and or condensed by the sea water and returns to the system. In their work, the method of re-use of excess low pressure steam energy and mass was studied as to get the sweet and fresh water, power and refrigeration with the help of organic Rankine cycle having an organic operating fluid of trans-butene, and with the optimal cyclic design, tried to provide a guideline for the use of these valuable energy. Concurrent production of sweet and fresh water, production of a significant amount of electricity and refrigeration with industrial and non-industrial purposes are the characteristics of this system.

3.4.1 Analytical set up and Working process of the system

A steam turbine generator one of the old petrochemical plantswith a capacity of 25 MW was chosen to get the steam with 19 bar and 25 bar pressure. According to the data of that petrochemical plant, the amount of surplus waste low pressure steam (LPS) in plant after expansion in turbine is 10 tonnes/hr having temperature 130^{o}C and pressure 2.7 bar. LPS steam has saturated conditions and transfers itslatent heat of evaporation in the heat exchanger (HX) cycle of power and cooling production into the operating fluid. A saturated liquid like, called low pressure condensate (LPC) is coming out of HX. Trans-butene is an operating fluid which is pumped to the shell & tube heat exchanger (HX). It is partially evaporated by the condensing LPS. The evaporated part of operating fluid is separated in a flash drum and introduced to the expansion turbine to produce power (electricity).

The liquid portion of trans-butene leavings flash drum joins to leaving portion of this fluid from expansion turbine. This stream is used as cooling or refrigeration media. The low pressure condensate stream leaving heat exchanger (LPC) is used as a boiler feed water. The process flow diagram of the cycle is presented in the fig. 14.

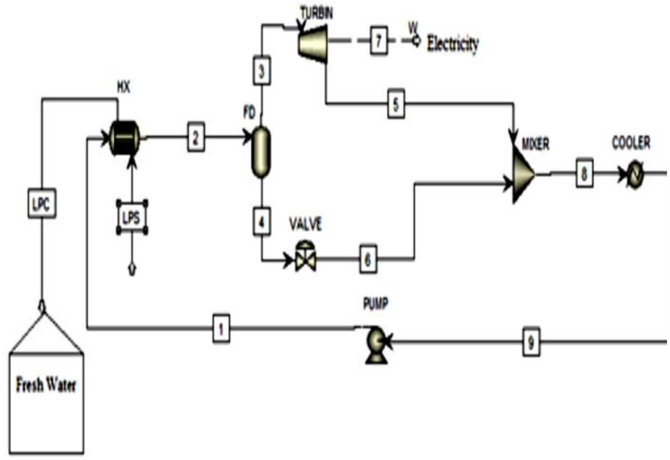

Figure 14. Concurrent production cycle of fresh water, electricity and refrigeration

3.4.2 Analysis of the process

The simulation is done in Hysys software and its result is presented in table 3. Stream number 2 which is the cold outlet stream of the HX converter has liquid and vapor phases. The higher the percentage of steam phase in this flow, more steam will be extracted by flash drum (FD). So, the amount of mass flow of stream 3 will be more and as a result of that, more electricity generated by the turbine. Hence, temperature of the hot outlet stream of the converter or that of LPC flow get reduced upto 47°C until the maximum thermal exchange between the two, hot and cold streams, are reached and thus it creates the maximum steam phase in stream 2. The operational temperature of flash drum affects the temperature of cold utility produced during power generation. It also affects the amount of power generation. These effects are presented in figures 15 & 16. According to these graphs the higher the flash drum temperature can produce more electricity and lower cold utility temperature which means more benefit. Fig.16, relating to the designed organic Rankine cycle cooler and signifies the total Duty amount on the basis of temperature and pressure. The summarized results of ORC application for heat recovery from surplus LP steam in petrochemical plant is presented in table 4.

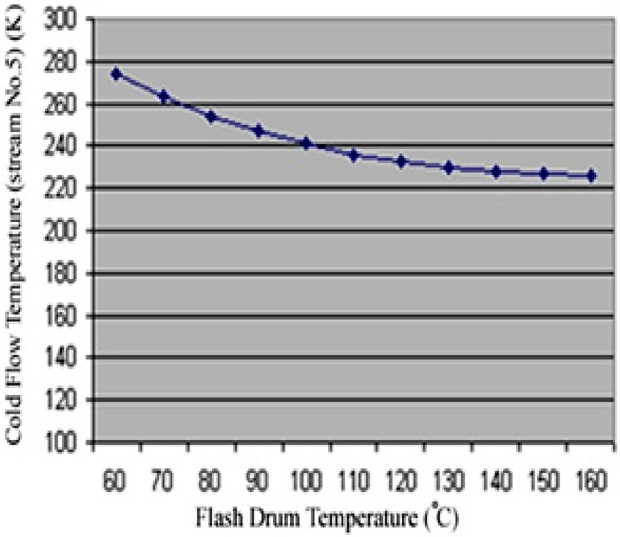

Figure 15. Flash drum temperature vs. Temperature of the produced cold stream

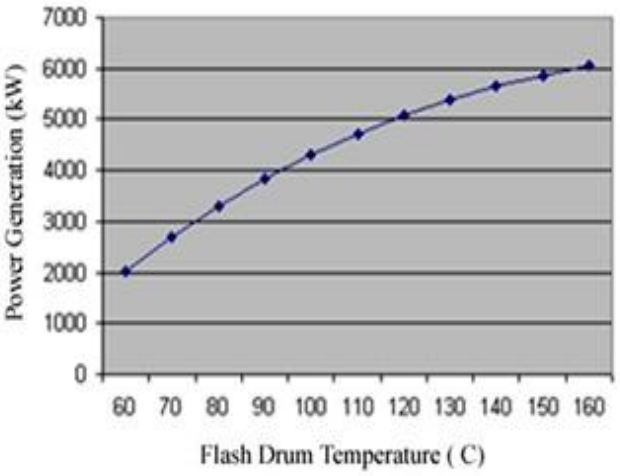

Figure 16. Flash drum temperature vs. Power generation

Table 3: Streams specifications

Stream No.	Compounds (kg/hr)	Temperature(K)	Pressure (atm)

1	0 / 70000	283	1
2	0 / 70000	273	1
3	0/42152	343	7.8
4	0/27847	343	7.8
5	0/42152	259	0.1
6	0/27847	225	0.1
8	0/70000	225	0.1
9	0/70000	283	0.1
LPC	10000/0	320	2.66
LPS	10000/0	403	2.66

Table 4: Simulation results for ORC cycle

	Stream	Production rate
Fresh water	LPC	10000 (kg/hr)
Electricity	7	1533 (kW)
Refrigeration	5	259.7(K)
	8	225.7(K)

The aforesaid cycle has not used any type of fossil energy sources, except the wasted energies. Therefore, its fuel consumption is zero and from the point of environmental issues, the system is absolutely clean and green. On the other hand, the produced distilled water in this system and the condensed LP steam will be used as compensatory water in the boilers or in other places. These types of cycles are low pressure system with no trouble and by the time of exploitation and operation they need no additional crews for control of the system.

II. CONCLUSION

As the energy demand in our day to day life escalates significantly, there are plenty of energies are shuffled in the universe. So it is imperative that a significant and concrete effort should be taken for using heat energy through waste heat recovery. The conclusion that can be drawn from this review work is that as much as 20 to 50% waste heat of the total energy consumed which is ultimately lost can be captured and reused for numerous applications using various existing and developing waste heat recovery technologies of efficient and economic design. Captured and reused waste heat is a valuable approach to improve overall energy efficiency by optimizing for costly purchased fuels or electricity and for the protection of global environment from pollution and rate of global warming. The feasibility of waste heat recovery requires characterizing the waste heat source and the stream to which the heat will be transferred. The waste stream parameters that must be determined include heat quantity, heat quality, composition, minimum allowed temperature, etc. This review paper concludes that from various research studies and analysis, refrigeration can be achieved quantitatively as well as qualitatively in different domains by using various waste heat recovery technologies. It can also be concluded that a huge annual energy savings and environmental benefits can be resulted by using these waste heat recovery technologies for refrigeration.

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