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Heat Storage System: A Modern Way to Reuse and Recycle Energy to Reduce Thermal Pollution

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ABSTRACT
Waste heat is a large amount of thermal energy, which is unused and emitted to the environment by some mechanical processes or, emitted from machines and machinery parts. Waste heat is always generated while producing mechanical output by using the temperature difference. Firstly, the paper deals with the study of waste heat produced in different types of power plants and industries. Secondly, designing the way to restore and reuse the waste heat produced as a by-product in the industries by implementing thermal storage system for lower temperatures, which is environment-friendly as well as efficient enough to restore and recycle a large amount of heat. The ways of enhancing the efficiency of heat storage, without disturbing the operational process of the furnace are prescribed thoroughly. The paper further deals with the feasibility of waste heat in the industries and shows its quality is good enough for different uses in the industries. Calculates the efficiency of the prescribed heat storage model, as well as the calculation of the net energy stored in the heat storage system, is also shown in the paper.

Keywords: Waste heat, Thermal storage, Heat loss, HTF, Water.

1. Introduction

In this era of industrialization, lots of importance is given to reducing the waste heat produced in different industries and power plants. There are also several technologies which are applicable to reuse the waste heat, produced in an industry because of different mechanical or thermal processes. Several processes can be done to store the heat emitted by these operations. One of them is the thermal heat storage system.

Thermal storages of small heat storing capacity can help nullify the variations on the load side introduced by minor disruptions of weather. e.g. by the appearance of clouds [1]. A large amount of energy is wasted in the industry as hot flue gas, emitted from machinery and heated products. To improve the energy efficiency of an industry, reusing of those waste heats is thought of as a very attractive way nowadays which can also help to reduce the production cost by saving fuel cost. This reduction of waste heat emission from industry can also contribute to making the whole process more nature-friendly as heat is a crucial factor for the greenhouse effect [2].

A large quantity of hot exhaust gases is produced from boilers, hot ovens, machinery outputs and furnaces of different types of plants. Though the energy lost in waste flue gases cannot be fully recovered and used. However, much of the heat could be improved and recycled by adopting the necessary procedures as prescribed in this study.

If a recovery process is designed for storing waste heat, then this heat can be reused when heat is needed for another unit like space and surface heating, water preheating for increasing boiler efficiency, combustion air preheating etc.

This paper deals with a brief discussion of short-term sensible thermal storage at low temperatures. We have considered here storage systems for different purposes like space heating and water pre-heating in industries and different types of power plants, systems in which the application temperature generally varies from 25˚C to 95˚C. Storage temperatures between 25˚C and 95˚C shall hence be considered in this paper.

2. Renewable waste heat sources for storing

In developing countries, there should be always some special application of renewable energy technologies for better production as well as to make the production cost-efficient. For the feasibility of waste heat recovery, the temperature of waste heat is a very important factor. It is must that waste heat temperature has to be greater than the temperature of the heat sink. Waste heat quality depends on the temperature difference between the source and the sink. Larger the difference better the quality of stored heat. The temperature difference between the source and sink effects on:

i. Heat transfer rate per unit area of the surface of the heat exchanger.
ii. The efficiency of the heat storage system

The higher the temperature of the waste heat, a heat storage system becomes more cost-effective and efficient. In the study of renewable waste heat, it is significant that there must be some use for the recycled exhaust gas heat or stored heat. Some examples of use would be preheating of air before combustion, space and surface heating, or boiler feed water pre-heating etc. [3].

The waste heat from exhaust gases range varies in different processes of production. Usually, the flue gases from industries and power plants like glass melting furnace, steel electric arc furnace, steam boiler exhaust, annealing furnace cooling, hydrogen plants etc. are some examples of plants and processes with higher temperature flue gases. This variation in temperature gives us the opportunity to classify the thermal storage system. Hence, waste heat qualities are classified

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dividing temperature ranges of the waste heat into three types:

i) Low
ii) Medium and
iii) High.

Various ranges and sources of different waste heat are as follow: [4]

Table 1 Classification of waste heat sources [4]

Temp. Range	Example Sources	Temp (°C)
High (>650˚ C)	Nickel refining furnace Steel electric arc furnace Zink refining furnace Copper furnace Hydrogen plants Open hearth furnace Glass melting furnace Fume incinerators Steel heating	1370-1650 1370-1650 760-1100 900-1090 650-980 650-700 1000-1500 650-1450 925-1050
Medium (230-650˚C)	Steam boiler exhaust Gas turbine exhaust Dying and baking oven Catalytic crackers Annealing Furnace Cooling System	230-480 370-540 230-600 425-650 425-650
Low (<230˚ C)	Cool water Furnace doors Welding machines Hot process liquids	32-55 32-88 32-232

3. Choosing a heat storage system

Thermal energy storage (TES) is the technology of storing thermal waste heat as thermal by heating or cooling a storage medium fluid so that, the stored thermal energy can be reused later for any other thermal operations.

There are three kinds of TES systems possible and those are as follow: [5]

i. Sensible TES system which is done on the basis of storing thermal energy with the help of heating or cooling a solid or liquid type storage medium (e.g. rocks, water, molten salts), with water-based storage being the cheapest option.
ii. Latent heat storage system which uses phase change materials or PCMs.
iii. Thermo-chemical storage (TCS) system which uses chemical reactions to store heat and release thermal energy later.

The following data in Table 2 Represents that, sensible heat storage technology is more cost-saving process than any other storage systems for lower temperature operations: [5]

Table 2 Different heat storage types [5]

Type of Storage	Capacity kWh/t	Efficiency (%)	storage period	cost(€ /kwh)
Sensible (hot water)	10-50	50-90	d/m	0.1-10
PCM	50-150	75-90	h/m	10-50
Chemical reactions	120-250	75-100	h/d	8-100

For choosing proper TES material for storing thermal energy efficiently, we have to think about its higher specific heat (Cp) and lower thermal conductivity (>0.3w/m-k). Also, the material should have a higher boiling point than waste heat temperature, suitable heat transfer fluid (HTF) should be chosen for better heat transfer. Water has the highest specific heat (4200J/kg-k). Hence, its heat capacity is large enough to be used as a storage medium, compared to other substances. So, it can store more thermal energy per unit of its weight. It is also non-toxic and available free of charge or at low cost in most of the countries [6].

But sensible heat storage using water as a storage medium is suitable only for those waste heat temperature below 100˚C. For low temperature (30-95˚C) waste heat, water is selected as thermal storage because of its higher specific heat. Though there are different types of heat recovery systems, this paper only deals with the low-temperature renewable waste heat recovery system and water is used as a heat transfer fluid.

4. Design of the proposed heat storage system

Fig.1 Shows the designed thermal heat storage system for lower temperatures.

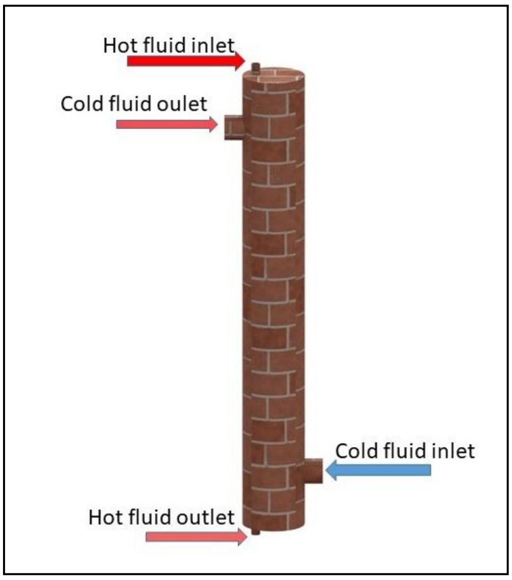
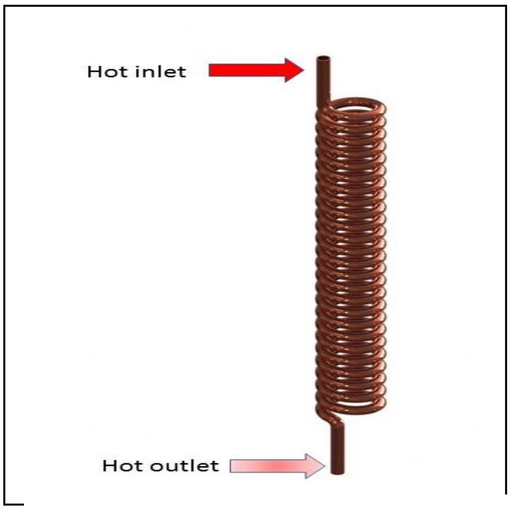


Fig.1 Heat storage model

In the prescribed design, for increasing contact surface area between hot and cold fluid we have used the helical tube. And due to lower heat capacity and higher value of thermal conductivity, we have used copper as the material of our helical tube which helped us to enhance heat transfer rate from hot to the cold fluid as well as increase the efficiency of our storage system. Also, the thickness of the spiral tube has been taken very small (0.5mm) for lowering thermal resistance of the pipe wall. The HTF was passed slowly through the helical copper tube so that, the quality of heat is not decreased. For making the storage thermally insulated, good insulating materials like fiberglass, brick wall etc. can be used. Brick is used in shell wall for better insulating performance in the above-mentioned thermal storage system. Fig.2 Shows the designed helical copper tube used in the thermal heat storage.



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5. Mesh generation and simulation analysis

We have performed a simulation of prescribed waste heat storage system via ANSYS (version 16.0) simulation software for analyzing the performance of our proposed design. Some assumptions and conditions were considered for this renewable waste heat storage design and simulation: [3]

a) The flow in the sensible heat storage mechanism is in steady flow condition.
b) Shell and helical tube type heat storage was used.
c) The mass flow rate of each fluid (both hot fluid and cold fluid) is kept constant without any variation with time.
d) Constant velocity of the fluids is considered, which is flowing through the storage system. So, kinetic and potential energy also considered being constant.
e) The outer shell surface of the storage system is thermally insulated and no heat transfer will occur between the storage wall and surroundings.

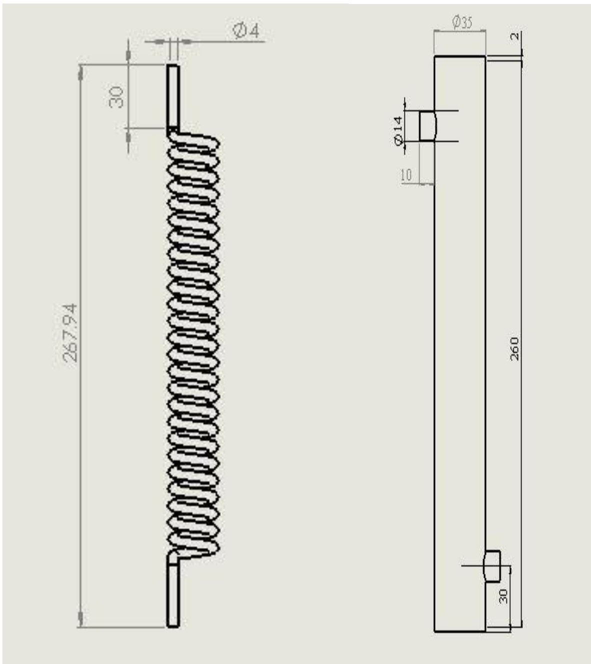


Fig. 4 Drawing view of spiral tube and shell

Fig.4 shows the drawing and necessary dimensions of the model that has been used in the modeling and simulation processes. Computational domain and value of different elements were taken as follow:
Coil Diameter = 20mm, Tube outer diameter = 5mm, Tube inner diameter = 4 mm, Tube thickness = 0.5mm, Coil length = 267.94mm;
Shell length = 260 mm, Shell diameter = 35 mm, Shell inlet diameter = 14mm, Shell outlet diameter = 14mm.

Here, the discretization of the fluid volume was done by following the principle of finite element analysis method. The mesh for the simulation process was generated using the mesh tools of ANSYS design modeler. Here, for meshing, coil body element size was

5×10^{-4}m and fluid domain element size was 5×10^{-4}m. The shell element size was 2×10^{-3}m and total element number was 6085921. The number of nodes was 1405023. Boundary Conditions for the simulation was as follow:
Cold inlet: Velocity inlet = 0.007ms^{-1},
Hot inlet: Velocity inlet = 0.05ms^{-1},
Cold outlet: Pressure outlet = 0 pa,
Hot outlet: Pressure outlet = 0 pa,
Cold fluid pressure drop in shell = 0.195pa,
Hot fluid pressure drop in tube = 264.1pa;

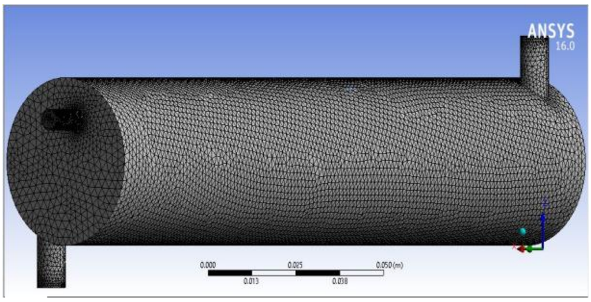
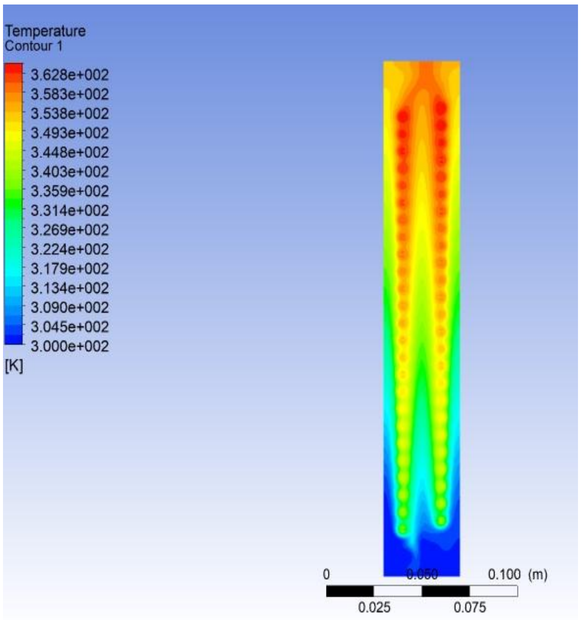


Fig. 5 Meshing of the heat storage system

Fig.5 represents the generated mesh of the heat storage system.
The result of the simulation is given below in fig.6 along with the output result of the simulation process:



Mass-Weighted Average Static Temperature	(k)
coldin	300
coldout	355.46385
hotin	365
hotout	333.70932
Net	341.55906

Fig.6 Simulation analysis of waste heat storage

Thus, from fig.6, the results of simulation provide us with a clear idea that, while using water as thermal storage for lower temperature. For 92˚C (365k) of the hot fluid inlet, we got 60.709˚C (333.709k) in the hot fluid outlet of the helical coil. We also used water as a heat transfer fluid (HTF). Again, the cold water will intake transferred heat, so the inlet temperature of the cold fluid in the storage tank is 27˚C (300k) and outlet 82.46˚C (355.46K). The rise in temperature of the cold-water outlet is caused due to waste heat.

The accuracy of the simulation depends on the number of elements and nodes. With the increase in the number of elements as well as nodes in the finite element analysis we can find the results more accurately So, we used a higher number of nodes and elements to find accurate results.

So, the simulation shows that the waste heat can be used to store up as thermal energy with this process by transferring the heat to a storage medium (cold fluid).

6. Energy stored and efficiency calculation

The amount of stored heat in the prescribed heat storage and the efficiency of the storage is as follow:
5.1 Stored heat
The net amount of energy that can be stored in the prescribed sensible heat storage depends on the temperature change of the storage material and can be expressed in the form as follow: [7]

$$E = m\int_{T_1}^{T_2} C_p\,dT \qquad (1)$$

Here, m is the mass of storage medium fluid and Cp signifies the specific heat of HTF (water), at a constant pressure. T_1 and T_2 denote the minimum and maximum temperature levels between which the storage operates. ($T_2 - T_1$) represents the temperature difference of the sensible waste heat thermal storage system. So, Equation (1) can be re-written as follow:

$$E = m.C_{P.}\,(T_2\text{-}T_1) \qquad (2)$$

Here, for per unit of volume of storage (v), and density of water (ρ), we can write-

$$E = \rho.v.C_{P.}\,(T_2\text{-}T_1) \qquad (3)$$

$$E = 1000\times1\times4200\times(82.46\text{-}27)$$

$$E=232.932\times10^{6}\ J$$

So, the net amount of energy that can be stored per unit volume of the prescribed heat storage is sufficient enough. It can be supplied and used for different purposes like space heating and water pre-heating in industries or, power plants and thus increase producibility without any loss of the extra amount of fuel.

5.2 Efficiency calculation

The efficiency of a heat storage system is defined as the ratio of the thermal energy extracted from the storage to the thermal energy stored in it. [7]

In this paper, we have used a thermal storage system, where hot fluid from our concerned industry, charging into our storage at 360K temperature through inlet point and leaving the system at 331.92842K temperature through outlet point. And our storage medium fluid water, charging at 300K temperature into storage system through inlet point and leaving at 326.81486K through outlet point by gaining thermal energy. Now efficiency can be written as:

$$\eta = \frac{\text{Thermal energy extracted from the storage}}{\text{Thermal energy stored in the storage}} \quad (4)$$

Equation (5) represents the efficiency of the thermal storage which can be further written as follow:

$$\eta = \frac{\dot{m}C(T_{co}-T_{ci})}{\dot{m}C(T_{hi}-T_{ho})} \quad (5)$$

Where,

$\dot{m}$ = Mass flow rate.

C = Heat capacity of the thermal storage medium.

T_{ci} = Inlet temperature of cold water.

T_{co} = Outlet temperature of cold water.

T_{hi} = Inlet temperature of hot water.

T_{ho} = Outlet temperature of the hot fluid.

V_c = Cold fluid velocity.

V_h = Hot fluid velocity.

ρ = Density of storage medium.

Now, from Equation (5), the value of efficiency have been obtained for the prescribed heat storage model as follow:

$$\eta = \frac{1000\times0.007\times1\times(355.46-300)}{1000\times0.049\times1\times(365-333.709)}$$

η = 25.32%

So, we can see the waste heat was used to store the thermal energy to the cold fluid and a large amount of heat was stored by this process. We can also get a clear idea about the efficiency of the prescribed storage system from the above-simulated data.

Another simulation was done by changing the hot inlet temperature from 365k to 360k. The cold inlet was kept 300k like the previous simulation. It was found that the hot outlet and cold outlet temperature changes along with the change of hot inlet temperature. For 360k hot inlet, the hot outlet temperature was found 331.92k and the cold outlet temperature was found 326.81k. When the efficiency reduces to only 13.64%. So the higher the difference of the temperature the higher the efficiency of the storage system.

Further improvement of efficiency is possible by choosing proper fluid velocity through the storage and varying heat transfer conditions.

7. Analysis of a blast furnace and reduction of thermal pollution

As a case study in a steel re-rolling mill (BSRM, Chittagong), a blast furnace was observed. The furnace is also named dual fuel furnace because two different types of fuels are used to run this blast furnace. They are natural gas and oil. The oils can be of two types. They are HFO oil and LDO oil. Even after completing all the desired works of this furnace, the flue gas (waste gas) still contains a high amount of heat which can be used as another source of thermal energy if it can be recycled as mentioned in this paper. To utilize this large amount of heat, the chemical components of flue gas should be observed and are given below: Main chemical components of flue (waste) gas for a blast furnace[8] are: water vapor, nitrogen (typical contents about 75-80%), carbon dioxide (typical contents 7-15%), carbon monoxide (CO) and hydrogen (H_2) due to incomplete combustion (typical contents 50-150 ppm), oxygen (O_2) due to excess of air (typical contents 2-8%), nitrogen oxides NO_X (NO+ NO_2) due to N_2 and O_2 combination at high temperatures (typical contents <100ppm.), sulfur dioxide (typical contents <200ppm.), unburned hydrocarbons and ashes. Typical sulfur content in HFO and LDO is accordingly (0.1-4.5%) (maximum) [9-10] and 1.2-1.8% (maximum).

This sulfur content is important because [11], to avoid the possibilities of corrosion due to the condensation of sulfur oxide gases, the temperature of the flue gas is to be kept above the dew point temperature of the sulfuric acid. It is observed that for about 5% sulfur content in flue waste gas, the sulfuric acid dew point temperature is about 150˚C. So, at an average 150˚C, the flue gas should be released in the environment to avoid the harm of corrosion and pollution on furnace operation. The observed furnace in a steel re-rolling mill (BSRM, Chittagong), releases waste heat at chimney exists in an amount of average of (200˚C to 300˚C) which is one type of medium temperature waste heat sources. So, it can be said that if the amount of waste heat in the chimney exit can be reduced by storing and can be kept at an average of 150˚C, it will be adequate to avoid corrosion of sulfur content and the operations of the entire furnace process will not be harmed. The rest 150˚C or more than it can be recovered and recycled by implementing heat storage systems as prescribed in this paper, for any type of process where such amount of heat is required. For example: boiling of water, surface heating, refrigeration process, room pre-heating etc.

8. Conclusion

Waste heat recovery is a significant concept that is another source of renewable energy as well as a way to make industries and power plants more efficient. In this paper, we have discussed various possible waste heat sources and types of heat storage system depending upon waste heat temperature, also showed a low cost and efficient heat storage system with better HTF like water. A simulation analysis of the prescribed storage system is shown properly along with the detailed mesh generation data. Hence, with the help of simulated data, the net energy stored per unit volume was measured. Then, the efficiency of the storage system is calculated. The net stored energy per unit volume of the storage medium is 232.932×10^6 J and efficiency is about 25%. The efficiency indicates that a good quality and quantity of stored heat can be used further in different industrial processes and productions. The application of stored heat is also shown in this paper along with the thermal pollution reduction possibilities in an industry. Finally, we can say that, in a country like Bangladesh, which is yet to be developed, waste heat can be another alternative source of energy which can provide the required energy to different fields and thus can reduce the wastage of energy by eliminating the wastage of thermal energy.

NOMENCLATURE

c_p : specific heat at constant pressure, $kJ\cdot kg^{-1}\cdot K^{-1}$
ρ : density of fluid, $kg.m^{-3}$
E : energy stored, kJ
p : pressure, kPa
T : temperature, K
V : volume, m^3

REFERENCES

[1] A. Abhat. Short term thermal energy storage. Revue de Physique Appliquee, 1980, 15 (3), pp.477-501.

[2] https://beeindia.gov.in/ (accessed 28/09/2017)

[3] Chowdhury, Tamal & Salam, Bodius & Chowdhury, Hemal & Barua, Pranta. (2018). “Waste Heat Thermal Storage ,A Way to Renewable Energy”.

[4] waste heat recovery-Bureau of Energy Efficiency, https://www.beeindia.gov.in/sites/default/files/2Ch8.pdf

[5] S. Khare n, M.Dell'Amico, C.Knight,S.McGarry “Selection of materials for high temperatures sensible storages” Solar Energy Materials & Solar Cells 115 (2013) 114–122

[6] http\\.Wikipedia.org/wiki/Hot_water_storage_tank

[7] O. Ercan Ataer, (2006), “STORAGE OF THERMAL ENERGY”, in Energy Storage Systems, [Ed. Yalcin Abdullah Gogus], in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford ,UK, [http://www.eolss.net]

[8] www.eurotron.co.kr/ (accessed 28/09/2017)

[9] www.marquard-bahls.com/ (accessed 29/9/2017)

[10] www.eecpowerindia.com/ (accessed 29/09/2017)

[11] https://mrpl.co.in/ (accessed28/9/2017)