DESIGN AND DEVELOPMENT OF WASTE HEAT RECOVERY FOR FILE CLEANING OPERATION BY USING FIN TYPE HEAT EXCHANGER

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Abstract

Waste energy in any industry plays an influencing factor in the overall efficiency of the plant. Utilizing the available energy in the industry is an essential thing; this can be achieved by installing the waste heat recovery system. Therefore, in this paper, the focus is to design and develop waste heat recovery system and its experimental validation for the file cleaning operation. The available literature was thoroughly reviewed and design processes of the fin type were studied. Review of research study concluded that heat quantity, waste stream temperature and waste stream composition are important parameters for designing of waste heat recovery system. Recovery of waste heat can be done by using heat exchangers. Heat transfer area, overall heat transfer coefficient, thermal conductivity of the material, mass flow rate hot and cold fluid and their temperature are very important parameters for designing of heat exchanger. This method it is an efficient way to recover waste heat from file drying operation. In this paper, the stepwise procedure for design of fin type heat exchanger has been formulated. After installing the fin type heat exchanger; readings are recorded by changing the mass flow rate, load on the diesel engine to evaluate the performance of the fin type heat exchanger. Installation of waste heat recovery system containing fin type heat exchanger greatly influence on the total expenditure spends on file cleaning operation. Due to preheating, the required energy for heating up the water in file cleaning operation get reduced and ultimately operational cost for heating get reduced.

Keywords – Heat quantity, Waste stream temperature, Stream composition, fin type heat exchanger, etc

Introduction

For the betterment of any organization, economic utilization of energy is the key factor. In this regard, effective utilization of the available energy is crucial. In manufacturing industry there are various machines that consume energy resources for carrying out particular operation. In the organization the machines like dryer gives out exhaust gases through which heat energy is getting wasted. Recovery of heat energy from these exhaust gases is a profitable option for the industry. This recovered energy can be further utilized for various operations in a plant which require heat. The recovery of heat can be achieved by means of heat exchanger.

A heat exchanger is a device used to transfer heat between a solid object and a fluid or between two or more fluids. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. In this case, the preferable type heat exchanger is fin type heat exchanger as one of the fluids is gas and other one is liquid. Fins are commonly used in extended surface heat exchangers. To minimize the size of heat exchangers, fins are used on the gas side to increase the surface area and the heat transfer rate between the heat exchanger surface and the surroundings. Both the conduction through the fin cross section and the convection over the fin surface area take place in and around the fin. When the fin is hotter than the fluid to which it is exposed then the fin surface temperature is generally lower than the base (primary surface) temperature. If the heat is transported by convection to the fin from the ambient fluid, the fin surface temperature will be higher than the fin base temperature, which in turn reduces the temperature differences and the heat transfer through the fin. Exchangers with fins are also used when one fluid stream is at high pressure. The temperature value is limited by the type of material and production technique. All above causes that finned tube heat exchangers are used in different thermal systems for applications where heat energy is exchanged between different media. Applications range from very large to the small scale.

Mr. Rupesh Suryavanshi and Prof. A. D. Pitale [2017] presents a review of various works focused on waste heat in industry for improving energy efficiency in their paper. The different reviews based on the aspects of heat recovery and the methodologies and technologies being employed for its optimization in industries also study through literature. This work also concentrated on the different parameters governing the waste heat recovery in the industries.[4]

Daniele Fiaschi, Giampaolo Manfrida, Luigi Russo and Lorenzo Talluri [2017] has proposed the improvement of low temperature exhausts heat recovery network of an industrial textile – drying machine (Stenter/Rameuse). A complete redesign of the layout of the water – gas heat exchangers network was done. The network was improved changing the original serial configuration of the heat recovery cells to a system with parallel manifolds for the water circuit. The heat transfer layout and the related heat exchangers were modeled with a dedicated thermal design code.[5]

While studying all the research papers mentioned in reference, it is observed that the feasibility of waste heat recovery system should be taken into consideration. The heat quantity is very important parameter as it describes the amount of heat contained in a waste stream and it also gives idea about usefulness of waste heat. Another parameter which should be taken into account is waste stream temperature. Material selection should be in accordance with waste stream composition as it also affects the heat recovery process. Use of heat exchanger in waste heat recovery system is profitable and most preferable option. Heat transfer area, overall heat transfer coefficient, thermal conductivity of the fin and tube material, mass flow rate hot and cold fluid and their temperature are very important parameters. These parameters greatly influence on designing and ultimately working of the heat exchanger, so they should take into consideration during design process.

Methodology

There are various manufacturing processes which are performed in the organization for production of file. One of such operation is drying of file. In this operation large amount of heat is getting wasted (through exhaust gases). Hence, this paper is to design a fin type heat exchanger to preheat the water so that the heat which is getting wasted can be recovered. The heated water is used in file cleaning operation. File drying operation is alike any other typical drying operation. In this, a heater is implanted at a bottom of the setup. This is functioned to heat up the air. A fan is incorporated, which circulates the hot air above the files. This results in drying of the wet files. The flue gases are thrown out of the plant. This heat energy in the hot gases remains unutilized.

In file cleaning operation, the files are immersed in the hot water to remove all dirt or foreign particles from the file and files get cleaned. The hot water required is made available by heating up the water with the help of electric heater.

The electric heater is a device used to heat up the water at the expense of electricity. The rating of electric heater used in the industry is 12 KW. Due to higher rating of electric heater it consumes a lot amount of electricity. This results in increasing the electricity bill. As discussed earlier, to improve plant efficiency, it is important to optimize use of available energy sources. Therefore, the heat energy, which is getting wasted through hot exhaust gases, can be utilized for another operation. Recovering this heat, the water gets preheated for file cleaning operation. This reduces the heat duty required to attain the operating temperature of file cleaning operation i.e. 80^{o}C by some extend. This heat recovery can be achieved by heat exchanger. As one of the fluids is liquid and other one is gas so best suited heat exchanger is fin type heat exchanger. Also, this is compact and its effectiveness is high.

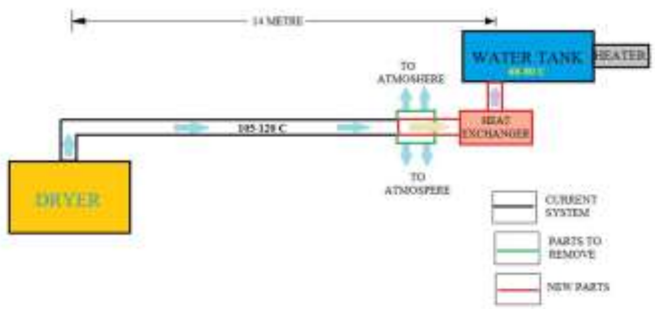

Figure 4.4 Proposed waste heat recovery system in the industry

The design of fin type heat exchanger is a very complicated and tedious job. This paper tends to simplify the design procedure and expected results have also achieved through experiment too.

Design of fin type heat exchanger

As discussed above, the fin type heat exchanger is used to transfer the heat energy between gas and liquid. In this paper the heat is taken out from the exhaust gases generated in the file drying operation and get transferred to the water for preheating, which will get utilized in file cleaning operation. The manufactured fin type heat exchanger is as shown in image:

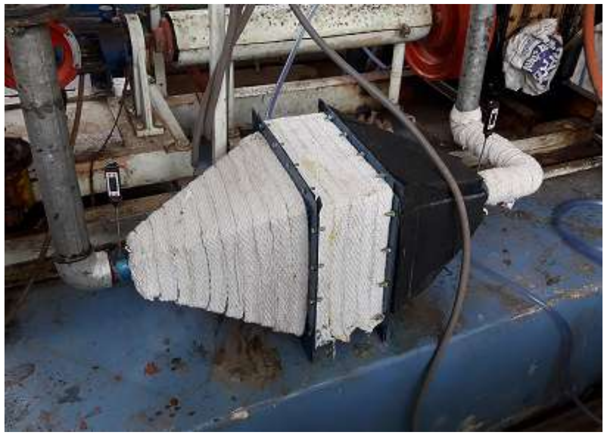

Figure 4.5 Fin type heat exchanger

1. **Selection of the process parameters**:-There are various important parameters for designing the fin type heat exchanger such as blower flow rate, water inlet temperature, rating of electric heater, diameter of tube, no. of fins, material used for both fin and tube, mass flow rate of water, water outlet temperature, gas inlet for fin type heat exchanger, tank capacity.

2. **Determination of heat transfer areas of fin and tube**: - The heat transfer increases as no. of fins increases. Due to no. of fins there is increase in cross sectional area. Hence fins are provided to improve the effectiveness of heat exchanger. The heat transfer area provided by tube is another deciding parameter for the better heat transfer rate.

3. **Determination of Reynolds no of water: -** Reynolds number is defined as the ratio of inertia force to viscous force. Reynolds number is denoted as Re.

$$Re = \frac{vd\rho}{\eta}$$

When Reynolds number is low, flow is laminar due to that heat transfer rate will be maximum.

4. Determination of Nusselt no of water: - Nusselt number (Nu) can be defined as the ratio of convective heat transfer to conductive heat transfer across the boundary.

$$Nu = CRe^{p}$$

The value of the constants for above equation can be taken from the table given below

Table 4.1 Values of constants for various Reynolds number

Reynolds number	C	P
30-1000	0.48	0.50
1×10^{3}-2×10^{5}	0.24	0.60
2×10^{5}-1.6×10^{6}	0.14	0.84

5. Determination of convective heat transfer coefficient (α_1): - Heat transfer coefficient is defined as the proportionality constant between the heat flux and the thermodynamic driving force for the flow of heat.

The overall heat transfer by combined modes is usually expressed on terms of an overall conductance or overall heat transfer coefficient

$$Nu = \frac{\alpha_1 d}{\lambda_w}$$

6. Determination of the Overall heat transfer coefficient and overall surface area ($U.A$) :- U stands for overall heat transfer coefficient. It is measure of the overall ability of a series of conductive and convective barriers to transfer the heat.

From above equation find value of the constant k_2

$$T_{co} = T_{ci} + \frac{\dot{m}_h.c_{p_h}}{\dot{m}_c.c_{p_c}}(T_{hi} - T_{ci})(1 - e^{-k_2})$$

$$k_2 = \frac{\dot{m}_c.c_{p_c}}{\dot{m}_h.c_{p_h}} \times (1 - e^{-k_1})$$

Using above equation calculate value of the k_1

$$k_1 = \frac{U.A}{\dot{m}_c.c_{p_c}}$$

and from above equation find the value of U.A

7. Determination of length of tube: - Values of all the terms of the equation are calculated in above procedure. Hence substitute all the values in the equation given below

$$\frac{1}{U.A} = \frac{1}{\alpha_f(A_2 + \varepsilon A_f)} + \frac{\delta_t}{\lambda_t.A_m} + \frac{1}{\alpha_1.A_1} \quad (1)$$

After the substitution, the only undetermined term is length of tube. After performing all calculation, the length of the tube is determined.

Sample Calculations:

1. Selection of the process parameters: - Various process parameters needed to be considered while designing the fin type heat exchanger. Selection of process parameters is the fundamental step while designing the heat exchanger.

a. Mass flow rate of water:
b. Assuming for water,
c. 1 kg = 1 litre
d. Tank with 80 litres capacity, has to be filled within 1 hour.
e. $\dot{m}_w = \dot{m}_c$

$$\dot{m}_c = \frac{80}{3600} = 0.0022\,kg/\text{sec} \quad (2)$$

f. Blower flow rate – 500 CFM
g. Achieved rate - 100 CFM (by using variable speed drive)
h. Water outlet temperature (T_{c_o})– 50° C
i. Rating of water heater-12 kW
j. Dimensions of heat exchanger–
    i. Pipe diameter – 3/8 Inches.
    ii. Fins – 14 Fins/inch
k. Material of the components –
    i. Casing – GI sheet
    ii. Tube – Copper
    iii. Fins – Aluminium

2. Determination of heat transfer areas of fin and tube: - Area of fin and tube is a parameter required to predict the heat transfer between the hot fluid and cold fluid.

Inside diameter of tube $= d_i = \frac{3}{8} inches = 0.0095mm$

Outside diameter of tube $= d_o = 0.0115mm$

Fin thickness $= \delta_t = \frac{d_o - d_i}{2} = 1\,mm$ (3)

Area of fin $= A_f =$ Area of rectangular fin $-$ Area covered by tubes

$= b_f l_f - n \times \frac{\pi}{4} \times {d_o}^2$ 0.050×0.26- 30 $\times \frac{\pi}{4} \times 0.00115^2$

$= 9.883 \times 10^{-3}\,m^2$

Considering 14 fins/inch and space available for fins $= 30cm = 11.81\,inches$

Total fin area $= A_f = 9.883 \times 10^{-3} \times 14 \times 11.81 m^2$ (4)

$A_f = 1.634 m^2$

Inside area of tube $= A_1 = \pi d_i L = \pi \times 0.0095 \times L \times 30 = 0.8953L\,m^2$ (5)

Outside area of tube $= A_2 = \pi d_o(L - nt) = 0.0361 \times (L - 2.16 \times 10^{-3}) \times 30\,m^2$ (6)

Average area of tubes $= A_m = \frac{A_1 + A_2}{2}$

Overall surface area $= A = A_f + A_2$

Heat conductance of tube material(copper) $= \lambda_t = 400\,W/m.K$

3. Determination of Reynolds Number of water: - Reynolds number is necessary to judge the nature of flow passing through the tubes. The flow may be laminar, transient or turbulent.

$$Re = \frac{vd\rho}{\eta}$$

Dynamic viscosity of water $= \eta = 8.90 \times 10^{-4} Pa.S$

Density of water $= \rho = 1000\, kg/m^3$

$d_i = 0.0095mm$

$$\rho = \frac{\dot{m_w}}{Q_w}$$

Volumetric flow rate of water $= Q_w = \frac{0.022}{1000} = 2.2 \times 10^{-5}\, m^3/sec$ $\qquad from\ eq.(2)$

$Q_w = V.A$

Inside area of tube $= A_i = \frac{\pi}{4} \times {d_i}^2 = 7.088 \times 10^{-5} m^2$

Velocity of water $= V = \frac{Q_w}{A} = \frac{2.2 \times 10^{-5}}{7.088 \times 10^{-5}} = 0.31\, {}^{m}/_{sec}$

$$Re = \frac{0.31 \times 0.0095 \times 1000}{8.9 \times 10^{-4}} = 3308.98 \qquad (7)$$

4. Determination of Nusselt Number of water: - Nusselt number gives idea about variation of the conduction and convection due to variable Reynolds number. Higher Reynolds number specifies very efficient convection.

$Nu = CRe^p$

So, values of C and p are

$C = 0.24, p = 0.6$ $\qquad (From\ table\ 4.1)$

$Nu = 0.24 \times (3308.98)^{0.6}$

$Nu = 31.047$ $\qquad (8)$

5. Determination of convective heat transfer coefficient($\boldsymbol{\alpha_1}$): - It is used in calculating the heat transfer typically by convection i.e. fluid and solid. The heat transfer coefficient is often calculated with help of Nusselt number

$$Nu = \frac{\alpha_1 d}{\lambda_w}$$

heat conductivity of water $= \lambda_w = 0.608\, W/mK$

$$31.047 = \frac{\alpha_1 \times 0.0095}{0.608}$$

Convective heat transfer coefficient $= \alpha_1 = 1987.008\ W/m^2K$ $\qquad (9)$

6. Determination of Overall heat transfer coefficient and overall surface area ($\boldsymbol{U.A}$)

Overall heat transfer coefficient is an ability of a series of conductive and convective resistances to the heat. For the case of a heat exchanger U can be used to determine total transfer between the two streams.

$$T_{co} = T_{ci} + \frac{\dot{m}_h.c_{p_h}}{\dot{m}_c.c_{p_c}}(T_{hi} - T_{ci})(1 - e^{-k_2})$$

$$50 = 25 + \frac{0.125 \times 1.9996}{0.022 \times 4.187} \times (80 - 25)(1 - e^{-k_2})$$

$25 = 3158.22 \times (1 - e^{-k_2})$

$k_2 = 0.1838$

$$k_2 = \frac{\dot{m}_c.c_{p_c}}{\dot{m}_h.c_{p_h}} \times (1 - e^{-k_1})$$

$$0.1838 = \frac{0.022 \times 4.187}{0.125 \times 1.996} \times (1 - e^{-k_1})$$

$k_1 = 0.6889$

$$k_1 = \frac{U.A}{\dot{m}_c.c_{p_c}}$$

$$0.6889 = \frac{U.A}{0.022 \times 4.187}$$

$UA = 0.06345\, kJ/K$ $\qquad (10)$

7. Determination of length of tube: - For better saturation of water high heat transfer area is deciding parameter & heat transfer area is enhanced by providing largerer length of the tube. More length more will be the saturation and better will be the heat transfer.

Let, Effectiveness $= \varepsilon = 0.7$ and Fin heat transfer coefficient $= \alpha_f = 75\, W/mK$

Substituting all values in equation (1)

$$0.0157 = \frac{1}{75 \times [1.083 \times L + (0.7 \times 1.634)]} + \frac{1}{0.8953L \times 400} + \frac{0.001}{400 \times \left(\frac{0.8953L + 0.0361 \times (L - 2.16 \times 10^{-3}) \times 30}{2}\right)}$$

$L = 0.38048m \approx 0.400m$

Results and Discussion:

In file manufacturing industry, the temperature required for file cleaning operation is 80℃. It is necessary to heat the water from ambient condition to required temperature.

In proposed solution, the water is preheated upto 50℃. In proposed solution using waste heat recovery system with fin type heat exchanger water is heated to a temperature of 50^0 C from ambient temperature i.e. 28^0 C is achieved theoretically. The energy required to reach 50^0 C to 80^0 C is less as compared to energy required to reach to 80^0 C from 28^0 C.

Percentage energy saved by the use of the heat exchanger:

Fraction of energy saved $= \frac{(\Delta T) with\ heat\ exchanger}{(\Delta T) without\ heat\ exchanger} = \frac{80 - 50}{80 - 25} = 0.5454$

Percentage energy saved = 54.54 %

Due to reduction in required amount of energy, the amount of electricity required for file cleaning operation is reduced and cost of electricity is saved.

Rating of water heater = 12 kW
Daily usage of water heater = 8 hr /day
Cost of electricity per unit = 7.10 Rs. /unit
Yearly expenses spend on water heating = Rating of heater ×Daily usage of water heater × Cost of electricity per unit × No. Of working days (let 300)
=12×8×7.10×300
=204480 Rs.

Saved money in a year = Fraction energy saved ×Yearly expenses spend on water heating
= 0.5454× 204480

Saved money in a year = 111523.39 Rs.

So, cost of heating up the water in file cleaning operation = Previous cost – Saved cost
= 204480 – 111523.39
= 92956.61 Rs

Table4.2 Results

Sr. No.	Parameters	Current Practice	Proposed Solution
1	Required temperature raise	80℃ − 25℃ = 55℃	80℃ − 50℃ = 30℃
2	Energy Consumption	100%	100-54.54 = 45.46%
3	Cost of water heating	204480 Rs	92956.61 Rs.

Conclusion

In an file manufacturing industry, the temperature of hot flue gases ranges from 80℃ to 120℃. In this temperature range, the designed heat exchanger has been validated. The results are quite satisfactory. The temperature achieved of cooling water is as per designed i.e. in the range 40℃ to 50℃.

After installation of fin type heat exchanger in industry, the heat which is getting wasted in file drying operation can be recovered and it is further utilized for file cleaning operation to preheat the water. The expenditure spend on heating water can be saved up to 54.54% i.e. 1 Lakh rupees.

Future scope

No matter how perfect the work is, there is always room for the improvement. In case of this paper i.e. waste heat recovery, the use of heat exchanger is preferable and profitable option. The effectiveness and efficiency of the heat exchanger can be improved.

For effective performance of heat exchanger, the insulation and leak-proof of heat exchanger casing is important. In validation, it is observed that there are some leaks in casing and insulation is not optimized. The casing can be leak proof by proper manufacturing and welding of the assembly. The insulation can be optimized by using high temperature insulators such as thermax jacket, mineral wool, ceramic blankets, etc.

For innovation of the heat exchanger, one can consider two points. First is tube and second is fin. The tube arrangement is one of the most influencing factors on the heat transfer in the heat exchanger. The arrangement can be changed or modified and optimum pattern can be incorporated. In the case of fin, the important parameters are its shape and quantity. There are various shapes of fins i.e. rectangular, offset strip, triangular, perforated, wavy and louvered fins. Each type of fin has its own their own specifications. So after taking different trials, selection of best suited fins can be done. Frequency of fins means number of fins at a particular distance. If more number of fins is used then heat transfer area will increase and this results in increase in heat transfer. But while deciding the quantity, one should also consider the possibility of choking of the gas.

Also, in any manufacturing industry, there are various types of equipment, which gives out heat as exhaust. There are many compressors and cooling towers in the plant. In industry one can achieve great saving in the energy by improving their respective efficiencies.

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