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RESEARCH ARTICLE

DESIGNING OF HEAT PIPE HEAT EXCHANGER FOR HEAT RECOVERY FROM SPRAY DRYER: CASE STUDY CHEMICAL UNIT AT AHMEDABAD, GUJARAT, INDIA

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ABSTRACT

This paper is based on project carried out at one Chemical unit at vatva, AhmedabadIt describes the recovery of waste heat from exhaust stream to preheat Spray-Dryerinlet air and designing of Heat Pipe Heat Exchanger as a waste heat recoverysystem. The total cost of the Heat Pipe Heat Exchanger with installation is 5, 00,000INR. It is proposed that the implementation of the heat recovery system will save190.6 KJ/Sec energy. The payback period of this heat recovery system come to be4 months, this is very attractive. In the Vatva industrial Estate more than 30Spray Dryers are installed for various applications, which show the potential of theheat recovery system for Spray Dryer in the small & medium scale units in thevarious industrial estates.

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INTRODUCTION

A heat pipe is a simple device that can quickly transfer heat from one point to another. They are often referred to as the "superconductors" of heat as they possess an extraordinary heat transfer capacity & rate with almost no heat loss. It consists of a sealed aluminum or copper container whose inner surfaces have a capillary wicking material. A heat pipe is similar to a thermosyphon. It differs from athermosyphon by virtue of its ability to transport heat against gravity by an evaporation condensation cycle with the help of porous capillaries that form the wick. The wick provides the capillary driving force to return the condensate to the evaporator. The quality and type of wick usually determines the performance of the heat pipe, for this is the heart of the product. Different types of wicks are used depending on the application for which the heat pipe is being used.

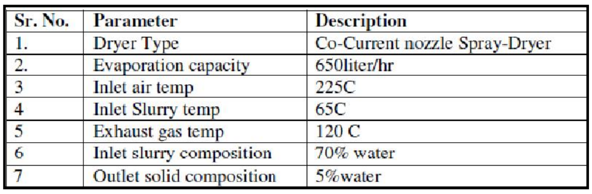
Background of the Project: Chemical Unit for which this exercise is conducted is involved in the manufacturing of the Acid Dyes. It is one of the prominent and most reputed manufacturer of the Dyes in the GIDC. It is a totally Export oriented Unit. It has the installed capacity of200MT/Month. Right now they are utilizing the capacity at 100 MT/Month. During the production of the Acid Dyes it is needed to dry out the wet Dye as one of the process step.

This Chemical Unit is using the Spray Dryer for carrying out the drying operation. They are having 2 Spray dryers. They are using it for drying of various dyes. The first dryer is having the evaporating capacity of650 lit. /hr. The second dryer is having the evaporation capacity of 750 lit./hr. The available data from designing of the Heat Recovery System for the Spray Dryer for Chemical Unit are as follows.

Heat Pipe Heat Exchanger design considerations

The three basic components of a heat pipe are:

- The container
- The working fluid



Sr. No.	Parameter	Description
1.	Dryer Type	Co-Current nozzle Spray-Dryer
2.	Evaporation capacity	650liter/hr
3	Inlet air temp	225C
4	Inlet Slurry temp	65C
5	Exhaust gas temp	120 C
6	Inlet slurry composition	70% water
7	Outlet solid composition	5%water

- The wick or capillary structure

Container

The function of the container is to isolate the working fluid from the outside environment. It has to therefore be leak-proof, maintain the pressure differential across its walls, and enable transfer of heat to take place from and into the working fluid.

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Selection of the container material depends on many factors.

These are as follows

- Compatibility (both with working fluid and external environment)
- Strength to weight ratio
- Thermal conductivity
- Ease of fabrication, including welding, machine ability and ductility
- Porosity
- Wet ability

Most of the above are self-explanatory. A high strength to weight ratio is more important in spacecraft applications. The material should be non-porous to prevent the diffusion of vapor. A high thermal conductivity ensures minimum temperature drop between the heat source and the wick.

Working fluid

A first consideration in the identification of a suitable working fluid is the operating vapor temperature range. Within the approximate temperature band, several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered.

The prime requirements are:

- compatibility with wick and wall materials
- good thermal stability
- wet ability of wick and wall materials
- vapor pressure not too high or low over the operating temperature range
- high latent heat
- high thermal conductivity
- low liquid and vapor viscosities
- high surface tension
- acceptable freezing or pour point

The selection of the working fluid must also be based on thermodynamic considerations which are concerned with the various limitations to heat flow occurring within the heat pipe line, viscous, sonic, capillary, entrainment and nucleate boiling levels. In heat pipe design, a high value of surface tension is desirable in order to enable the heat pipe to operate against gravity and to generate a high capillary driving force. In addition to high surface tension, it is necessary for the working fluid to wet the wick and the container material i.e. contact angle should be zero or very small.

The vapor pressure over the operating temperature range must be sufficiently great to avoid high vapor velocities, which tend to setup large temperature gradient and cause flow instabilities. A high latent heat of vaporization is desirable in order to transfer large amounts of heat with minimum fluid flow, and hence to maintain low pressure drops within the heat pipe. The thermal conductivity of the working fluid should preferably be high in order to minimize the radial temperature gradient and to reduce the possibility of nucleate boiling at the wick or wall surface. The resistance to fluid flow will be minimized by choosing fluids with low values of vapor and liquid viscosities. Tabulated below are a few mediums with their useful ranges of temperature.

Wick or Capillary Structure

It is a porous structure made of materials like steel, aluminum, nickel or copper in various ranges of pore sizes. They are fabricated using metal foams, and more particularly felts, the latter being more frequently used. By varying the pressure on the felt during assembly, various pore sizes can be produced.
By incorporating removable metal mandrels, an arterial structure can also be molded in the felt. Fibrous materials, like ceramics, have also been used widely. They generally have smaller pores. The main disadvantage of ceramic fibers is that, they have little stiffness and usually require a continuous support by a metal mesh. Thus while the fiber itself maybe chemically compatible with the working fluids, the supporting materials may cause problems. More recently, interest has turned to carbon fibers as a wick material. Carbon fiber filaments have many fine longitudinal grooves on their surface, have high capillary pressures and are chemically stable.

A number of heat pipes that have been successfully constructed using carbon fiber wicks seem to show a greater heat transport capability. The prime purpose of the wick is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. It must also be able to distribute the liquid around the evaporator section to any area where heat is likely to be received by the heat pipe. Often these two functions require wicks of different forms.

The selection of the wick for a heat pipe depends on many factors, several of which are closely linked to the properties of the working fluid. The maximum capillary head generated by a wick increases with decrease in pore size. The wick permeability increases with increasing pore size. Another feature of the wick, which must be optimized, is its thickness. The heat transport capability of the heat pipe is raised by increasing the wick thickness.

The overall thermal resistance at the evaporator also depends on the conductivity of the working fluid in the wick. Other necessary properties of the wick are compatibility with the working fluid and wet ability. The most common types of wicks that are used are as follows:

Sintered Powder

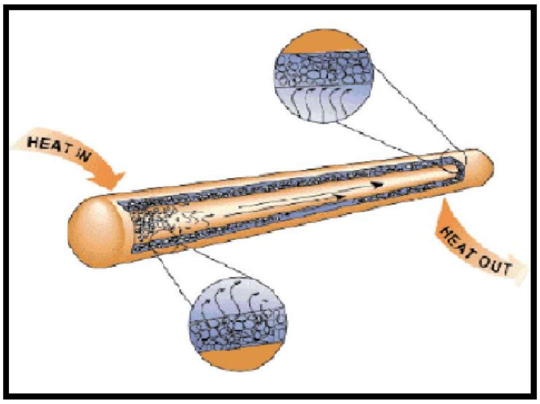
This process will provide high power handling, low temperature gradients and high capillary forces for anti-gravity applications. The photograph shows a complex sintered wick with several vapor channels and small arteries to increase the liquid flow rate. Very tight bends in the heat pipe can be achieved with this type of structure

Grooved Tube

The small capillary driving force generated by the axial grooves is adequate for low power heat pipes when operated horizontally, or with gravity assistance. The tube can be readily bent. When used in conjunction with screen mesh the performance can be considerably enhanced.

Screen Mesh

This type of wick is used in the majority of the products and provides readily variable characteristics in terms of power transport and orientation sensitivity, according to the number of layers and mesh counts used.



Working

Inside the container is a liquid under its own pressure, that enters the pores of the capillary material wetting all internal surface. Applying heat at any point along the surface of the heat pipe causes the liquid at that point to boil and enter a vapor state. When that happens, the liquid picks up the latent heat of vaporization. The gas, which then has a higher pressure, moves inside the sealed container to a colder location where it condenses. Thus, the gas gives up the latent heat of vaporization and moves heat from the input to the output end of the heat pipe. Heat pipes have an effective thermal conductivity many thousands of times that of copper.

The heat transfer or transport capacity of a heat pipe is specified by its “Axial Power Rating (APC)". It is the energy moving axially along the pipe. The larger the heat pipe diameter, greater is the APR. Similarly, longer the heat pipe lesser is the APR. Heat pipes can be built in almost any size and shape.

Energy savings

- Inlet slurry composition 70% water
- Outlet solid composition 5% water
- Inlet hot air temperature 225^0C
- Slurry inlet temperature 79^0C
- Exhaust gas temperature 120^0C
- Air inlet flowrate 5kg/hr
- Calorific value LDO 42636 kJ/lit
- Heat delivered by LDO = 764kW
- Evaporation capacity of spray dryer = 0.1799 kg/ hr
- Humidity of exhaust gas = 0.03
- Saturated humidity of exhaust gas = 0.08
- Percentage humidity of exhaust gas = 37.5%
- Humid heat of exhaust Cs=1.295kJ/kg^{0}C
- Enthalpy of Exhaust gas = 635.36kw
- Heat recovery is 30% of exhaust heat
- Recovered heat =190.6kw
- Price of LDO =25Rs/lit
- Price of 42636kJ is 25Rs
- Price of 190kw is = 0.11Rs/sec
- Spray dryer operated 20hr in day & 200 days in a year =7920 Rs/day = 1584000 Rs/year
- Total cost of Heat Pipe Heat Exchanger =500000Rs
- (Equipment cost + Installation Cost)

Hence, payback period=4 months Heat Pipe Recovery System design

Choose as the first possibility a set of finned heat pipes having the same geometry as the0.774-in. OD finned tubes.

The key dimensional data using theB spacing are

Tube OD = 19.65 mm
Fin OD = 37.2 mm
Fin Thickness = 0.305 mm
Fin Spacing = 0.305 mm
Fin area/total area = 0.835
Free flow area / Inlet face area = 0572
Heat transfer area / total volume = 279 m^2/m^3
Equivalent passage diameter = 8.21 mm
Tube spacing = 50.4 X 44.5 mm

For a first trial use a Reynolds number of 3000 for which the chart gives a value of 0.00715 for the heat transfer parameter. The physical properties of the fluid streams for an average heat pipe metal temperature of 93^0C can be obtained from table H2.4 that is, the specific heat is 1.011 kJ/kgC , the viscosity 0.2146 X 10-4 Pa.s, and the Pr and tl number 0.685.

Using these values we obtain

G = 3000 X 0.2146 X 10-4 / 0.00821= 7.85 kg/s. m ^{2}
h = 0.00715 X 7.85 X 1011 / 0.777= 73 W/m2C

Estimating the fin efficiency from literature data yields a value of 0.94, which can be combined with the ratio of fin area to total area of 0835 to give an effective heat transfer coefficient 95% of the above value. The temperature drop within the heat pipe can be estimated quickly from Table 6.2 which gives a radial temperature drop of 11.1^0C for a heat flux of 10 kW/m^2,so that the radial temperature drop would be about 2C,reducingthe effective temperature difference from 27.7^0C to25.7 ^{0}C

For the pure cross flow configuration and with the same weight and mass flow rates in the two streams, the temperature difference between the metal surface of the heat pipes and each gas stream will be uniform throughout the matrix, running 25.7^0C if the small temperature drop within the heat pipe is included. The weight flow per unit of inlet face area is 57.2% of the mass flow rate through the passages between the tubes, hence the amount of heat transferred in traversing a unit volume of the heat transfer matrix is

$Q = hAT$
$= 523\ \mathrm{kW} / \mathrm{m}^3$
The gas temperature rise per unit length would be
$T = Q / WCp$
$= 115\ {}^0\mathrm{C/m}$
The length of the matrix would be
$L = 0.725\ \mathrm{m}$

If the length of heat pipe in each gas stream is chosen to be 3m, the heat load on each heat pipe can be estimated by first calculating the number of heat pipes per meter of height and then the heat load per pipe.

Number of heat pipes/m of height = 323

Heat load / pipe= 3.63 kW

Referring to Fig. 6.7 to appraise the capacity of a heat pipe. It can be seen that the capacity of a 25.4 mm diameter heat pipe at the lowest temperature in the matrix for this application, namely, 65^0C, would be over 20 kW.

Conclusion

Given the rising cost of energy, the uncertainty surrounding deregulation and its effect on energy costs and availability, it makes sense to consider using an energy recovery device. During the feasibility study at Chemical Unit, it was found that the Spray Dryer exhaust temperature is 120 ^{0} C means the exhaust itself carries the high potential of heat recovery prospects, if the heat recovery system is employed. After doing the calculation from the available data, it is found that by implementing the Heat Pipe Heat Exchanger at Chemical Unit to recover the exhaust heat and recover the heat to preheat the Air inlet which itself will save 190.6 kW energy. The Economic Analysis also depicted that the implementation of Heat Pipe heat exchanger will cost total Rs.5, 00,000. By spending in the equipment cost & installation cost, it will save Rs.15, 84,000 annually which itself means that the Pay-back period for this project is just nearly 4 months ,which makes it very much attractive to implement.

While the analysis is somewhat involved, the results can demonstrate significant year over- year operating cost savings. This, in turn, can go a long way towards justifying any up front costs an energy recovery device. In addition, adding an energy recovery device may qualify for rebate rupees with the local gas or electric supplier, further offsetting the cost of the equipment.

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