ENTHALPY WHEEL APPLICATION FOR HEAT RECOVERY IN HEAT EXCHANGER

Mr. Vishal. P. Hegana[1], Prof. P.R. Kulkarni[2]

[1]PG Scholar, Heat Power Engineering Department,

J.J. Magdum College of Engineering, Jaysingpur, Kolhapur, Maharashtra (India)

[2]Associate Professor, Dean Academics, Mechanical Engineering Department,

J.J. Magdum College of Engineering, Jaysingpur, Kolhapur, Maharashtra (India)

ABSTRACT

A heat exchanger is a device built for efficient heat transfer from one medium to another. The medium may be separated by a solid wall, so that they never mix, or they may be in direct contact. Heat recovery system is one of the best applications of heat exchangers which use energy recovery ventilators.[1] Many options like rotary enthalpy wheel, heat pipe, thermo siphon, twin towers are available for heat recovery. Enthalpy wheel is an Energy Recovery Ventilator (ERV) consists of a rotating wheel partitioned by a hygroscopic membrane.[2] It is a regenerative type of heat exchanger. It exchanges sensible as well as total heat. Sensible heat is transferred through storage mass while moisture is transferred through hygroscopic material. Heat wheels typically have a sensible effectiveness of 50% to 80% and a total effectiveness of 55% to 85%. It is competitive than other ERVs in compactness and heat transfer effectiveness. These devices do not require special alignment as required by thermo siphons. They provide control over performance by adjusting the rotor speed. But it suffers high maintenance cost. Enthalpy wheels find application in recovery of heat from exhaust gases in Heating, Ventilation and Air-conditioning (HVAC) applications. It can be effectively installed in projects that require a large percentage of outdoor air and have the exhaust air duct in close proximity to the intake can increase system efficiency by using a heat wheel to transfer heat in the exhaust to either pre-cool or preheat the incoming air.

Keywords: Enthalpy Wheel, HRV, ERV, Latent Effectiveness

I. INTRODUCTION

1.1 What is Heat Exchanger?

Heat exchanger is a device in which the exchange of heat between two fluids at different temperature takes place. Heat exchanger utilizes the fact that where there is temperature difference, flow of energy occurs. The fluid which receives the heat is called cold fluid and the fluid which gives heat is called hot fluid. Basically heat exchangers work on phenomenon of convection.

1.2 Types of Heat Exchangers

- Direct transfer type:
  - Tube in tube type:
    - Parallel flow type
    - Counter flow type:

- Shell and tube type
  - Single pass
  - Multi pass
- Cross flow type:
  - One fluid mixed
  - Both fluids mixed
  - Both fluids unmixed

- Regenerator or Storage Type:
  - Stationary Matrix Type
  - Rotating Matrix Type
- Direct Contact Type:

1.3 Related Terms

1.3.1 Effectiveness

The heat exchanger effectiveness, ε, is defined as the ratio of the rate of heat transfer in the exchanger, Q, to the maximum theoretical rate of heat transfer i.e. Q_{max}

$$\varepsilon = \frac{Q}{Q_{\max}}$$

1.3.2 NTU

The number of transfer units (NTU) is an indicator of the actual heat transfer area or physical size of the heat exchanger. The larger the value of NTU, the closer the unit is to its thermodynamic limit. It is defined as

$$NTU = \frac{UA}{(\dot{m}c_p)_{\min}}$$

1.3.3 Capacity Ratio

The capacity ratio, C_r, is representative of the operational condition of a given heat exchanger and will vary depending on the geometry and flow configuration (parallel flow, counter-flow, cross flow etc.) of the exchanger. This value is defined as the minimum heat capacity rate divided by the maximum capacity rate i.e.

$$C_r = \frac{(\dot{m}c_p)_{\min}}{(\dot{m}c_p)_{\max}}$$

1.4 Applications of Heat Exchangers

- Space heating
- Refrigeration and air conditioning
- Power plants
- Chemical plants
- Petrochemical plants
- Petroleum refineries
- Natural gas processing

Heat exchangers are widely used in all areas of thermal engineering. The research work in heat exchanger has led to many advances. Scientists are mainly focusing on the areas like compact heat exchangers, heat recovery systems etc. We have mainly focused on rotary enthalpy wheel from heat recovery systems for HVAC applications.

II. ENERGY RECOVERY VENTILATION

It is the energy recovery process of exchanging the energy contained in normally exhausted building or space air and using it to treat the incoming outdoor ventilation air in residential and commercial HVAC systems. The benefit of using energy recovery is the ability to meet the ASHRAE ventilation & energy standards, while improving indoor air quality and reducing total HVAC equipment capacity. This is carried out by using energy recovery ventilators.

This technology has not only demonstrated an effective means of reducing energy cost and heating and cooling loads, but has allowed for the scaling down of equipment. Additionally, this system will allow for the indoor environment to maintain a relative humidity of 40% to 50%. This range can be maintained under essentially all conditions. The only energy penalty is the power needed for the blower to overcome the pressure drop in the system.

III. ENERGY RECOVERY VENTILATORS

3.1 Introduction to Energy Recovery Ventilators

An Energy Recovery Ventilator (ERV) is a type of air-to-air heat exchanger that not only can transfer sensible heat but also latent heat. Since both temperature and moisture is transferred, ERVs can be considered total enthalpic devices. On the other hand, a Heat Recovery Ventilator (HRV) is limited to only transferring sensible heat. HRVs can be considered sensible devices only because they exchange only sensible heat.

3.2 Types of Energy Recovery Devices

Energy Recovery Devices	Type of Transfer
Rotary Enthalpy Wheel	Total & Sensible
Heat Pipe	Sensible
Run Around Loop	Sensible
Thermo siphon	Sensible
Twin Towers	Sensible

Table: 3.1- Types of Energy Recovery Devices

Thermo siphon refers to a method of passive heat exchange based on natural convection which circulates liquid without the necessity of a mechanical pump. Its intended purpose is to simplify the pumping of liquid and/or heat transfer, by avoiding the cost and complexity of a conventional liquid pump.

Heat pipe is a device used to obtain very high rate of heat flow. The surface area required for heat transfer is relatively small. The heat transfer is obtained theoretically at isothermal conditions using latent heat of evaporation of a working fluid.

IV. ROTARY ENTHALPY WHEEL

The rotating wheel heat exchanger is composed of a rotating cylinder filled with an air permeable material resulting in a large surface area. The surface area is the medium for the sensible energy transfer. As the wheel rotates between the ventilation and exhaust air streams it picks up heat energy and releases it into the colder air stream. The driving force behind the exchange is the difference in temperatures between the opposing air streams which is also called the thermal gradient. Typical media used consists of polymer, aluminium and synthetic fibre.

The Enthalpy Exchange is accomplished through the use of desiccants. Desiccants transfer moisture through the process of adsorption which is predominately driven by the difference in the partial pressure of vapour within the opposing air-streams. Typical desiccants consist of Silica Gel and molecular sieves. Today energy recovery ventilation has arrived as mainstream technology for the HVAC The air-to-air heat exchanger, specifically the rotary exchanger known as a heat wheel or enthalpy wheel, would answer the need. Enthalpy wheels use the energy which is normally lost in the exhaust air to heat, cool, humidify or dehumidify the outside air as it is introduced into the building. Not a new idea, heat wheels were proven technology in use for several decades. Air exchange updated the technology with modern structural design and lightweight polymer materials. Improved maintainability, greater reliability and an expanded range of applications are the results of this industry.

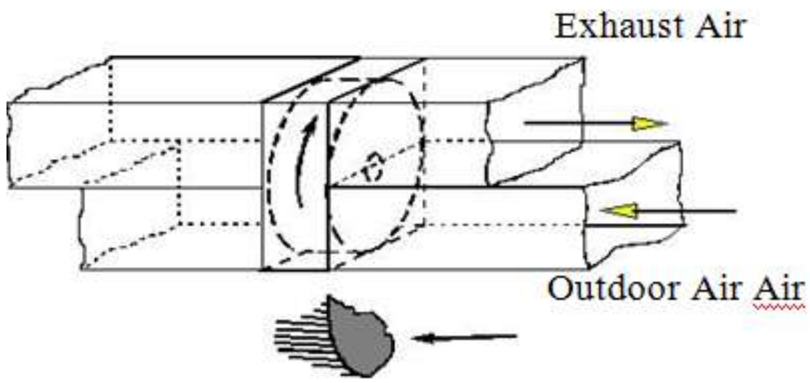

Fig. 4.1 Heat Conducting Material With Optional Desiccant Coating

4.1 Classification of Enthalpy Wheel

There are three types of enhtalpy wheels

- Sensible heat wheels
- Dehumidifier wheels
- Enthalpy wheels

For the same air inlet temperature these wheels are operate on same principle but due to its capability to transfer the moisture, we expect different humidity and outlet temperature.Performance characteristic of wheels are determined the physical properties of the porous matrix.

Sensible heat wheels require non-sorbing material with large thermal capacity since heating and cooling of air stream is desired.

Maximum moisture transfer is necessary in dehumidifier wheels, so they use max. sorbat material with large capacity of moisture capacity and low thermal capacity.

Sensible wheels are used for utilising exhaust heat. These wheels give great amount of heat recovery. The difference between enthalpy and desiccant wheels include:

Enthalpy wheels are designed for maximum exchange of humidity of sensible heat and desiccant are designed for maximum exchange of humidity. This affects the type and quantity of adsorbent materials used to coat the wheels. Enthalpy wheels are typically easier to clean and require more frequent cleaning because they handle more total air flow. Enthalpy wheel rotate faster up to 25 rpm and desiccant wheels are rotate only few times per hour.

4.2 Principle of Operation

4.2.1 Heat Transfer

The rotor with its axial, smooth air channels serves as a storage mass, half of which is heated by the warm air stream and half of which is cooled by the cold air stream, in a counter-flow arrangement. Consequently, the temperature of the storage mass varies depending on the axial coordinate (rotor depth) and on the angle of rotation. The principle of operation is easy to understand by following the condition of an air channel during one revolution (see following fig.). From this process, the following can be seen:

- The air temperature at the exchanger outlet is not uniform; it depends on the angle of rotation.
- The heat recovery efficiency may be influenced by adjusting the speed of rotation.
- The heat recovery efficiency may also be influenced via the storage mass: wider or narrower air channels, different thickness of the storage material, other rotor depth. These parameters also affects pressure drop.
- The specific heat output capacity depends on the temperature difference between the two air streams. Hence the rotary heat exchanger is suitable for heat as well as cool recovery, i.e. for winter and summer operation.

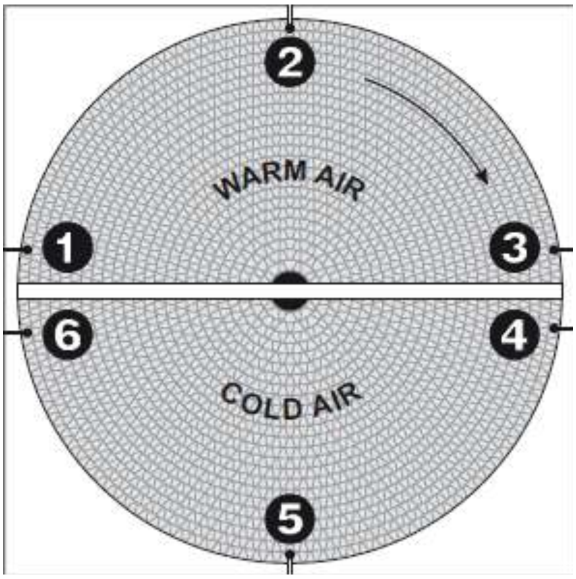

Fig. 4.2 Concept of Heat Transfer Through Wheel

1) Warm Air Entry

The wheel rotating at a speed of up to 20 rpm, the air channel has entered from the cold air into the warm air. The storage mass has been cooled down nearly to the cold air temperature. This applies particularly on the cold air inlet side (= warm air outlet). Now warm air flows through this channel, in counter-flow as regards temperature, and is severely cooled in this process. In turn, the storage mass is heated. The local heat recovery efficiency, i.e. directly at the entry into warm air, is very high. Condensation can occur easily.

2) Mid Warm Air

This air channel has already passed half of its time in the warm air. The storage mass has become warmer due to the arm air flow; consequently the warm air is no longer cooled as severely as in the entry zone. The channel temperature is about the same on the inlet side and on the outlet side. Condensation occurs only if the humidity differential is great.

3) Warm Air Exit

The air channel is on the verge of leaving the warm air. On the inlet side it has nearly reached the temperature of extract air. The heat transfer rate is now low. The duration of stay in the warm air as well as in the cold air, i.e. the speed of rotation, is decisive for the performance of the rotary heat exchanger. Also, the performance depends on the storage mass (thickness, geometry), the heat transfer and the air velocity.

4) Cold Air Entry

After pass over from the warm air side to the cold air side, cold air now flows through the channel (in counter-flow as regards temperature). Due to the large temperature difference the heat transfer rate is very high, i.e. the cold air is strongly heated; in turn, the storage mass is severely cooled. Possible condensate on the exchanger surface is (partly) taken up by the heated cold air.

5) Mid Cold Air

Half of the dwell time in the cold air is over. The storage mass has become markedly colder. Temperatures at the inlet and at the outlet are about the same.

6) Cold Air Exit

The air channel has gone through the cold air zone. The storage mass has been severely cooled; near the inlet the temperature has almost reached the temperature of cold air. After cross-over to the warm air side the cycle starts anew.

4.2.2 Moisture Transfer

Rotary heat exchangers can transfer moisture as well as heat. The decisive criterion for the transfer of moisture is the material or surface of the storage mass. The metallic storage mass has a capillary surface structure due to chemical treatment (pickling). Therefore (to a certain degree) moisture is transferred by sorption, i.e. without condensation. Depending on the air conditions, condensation may also occur.

4.3 CONSTRUCTION

A rotary heat exchanger consists of a rotor, a casing and an actuator.

4.3.1 Rotor

The rotor is assembled from alternate layers of flat and corrugated thin sheet aluminium. The smooth channels formed by this construction ensure that the flow is laminar, thereby ensuring that the drop is low and minimising the risk of fouling by dirt or dust. Dry particles up to 900 microns shall pass freely through the rotor without clogging the media. The rotor media can be cleaned with low temperature steam

The depth of the rotor is 200 mm. The wheel is strengthened by means of double spokes, which are bolted (and welded) in the hub and welded in the rotor shell ensuring a long life span. At the perimeter the rotor is enclosed by a welded aluminium shell, ensuring true running and allowing maximum use of the wheel face area.

Fig. 4.3 Rotor Strengthen by Double Spokes

4.3.2 Casing

Construction of casing depends on the size of the rotor. Casings are fabricated by using metal sheets. Casing may be single unit or partitioned. Casing supports rotor bearing with the help of the cross members and struts. It also encloses the motor unit.

Fig. 4.4- Sheet Steel Casing

4.3.3 Drive

The wheel is driven by means of an electric motor and a drive belt. The motor is usually fixed on a hinged plate in the casing. Drive provided can be constant or variable. Performance control (i.e. a variation of the heat or moisture recovery efficiency) is not possible in constant drive. In variable drive system, the rotor speed is varied as per room temperature. This is achieved by means of cascaded controllers which use rotary heat exchanger as energy resource in heating as well as cooling operation.

4.4 Enthalpy Wheel Desiccants

- Lithium Chloride: Salts dissolve, wash off.
- Silica Gel: Best water transfer characteristics.
- Molecular Sieves: Can be engineered to discriminate between species. Ideal for many process applications

4.5 Performance Control

Rotary heat exchangers always operate as a temperature moderator between the two air streams. The direction of the heat transmission is of no consequence, i.e. depending on the temperature difference between extract air and fresh air either heat or cool recovery takes place. Therefore performance control of the rotary heat exchanger is not necessary when the extract air temperature is identical with the desired room temperature. In this case, the fresh air is always either heated or cooled through the heat exchanger in the direction of the set temperature.[3]

In many cases, however, heat gains are present in the ventilated space (people, machinery, lighting, solar, process plants), which increase the room temperature, so that the extract air temperature is higher than the set temperature. In this case, at full performance of the heat exchanger, check at which outside temperature heat-up begins and if this cannot be tolerated the performance of the heat exchanger must be controlled.

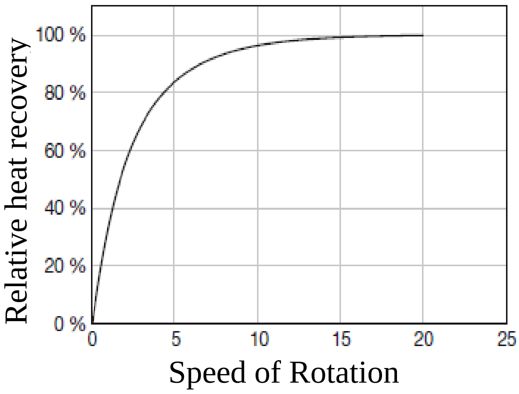

Fig. 4.5- Performance of a Rotary Enthalpy Wheel

4.6 Maintenance

As with any building systems and particularly air handling systems, proper maintenance will be essential to the successful function of the space.

Nowhere is this more evident than in the hospitality environment where ETS is present. The need for maintenance should be considered in the system design and equipment selection. A positive feature of all current enthalpy wheels is that they exhibit laminar flow within the heat and moisture exchange surface. (Packed bed and mesh type wheels exhibit turbulent .generally specified for comfort conditioning applications.)[4] In addition, the transfer of water into and out of the desiccant surface occurs in the vapour phase; no wet surfaces are presented to the airstream. As a result, the wheel surfaces do not act as an impact filter and particulate matter small enough to enter the wheel will pass through. Larger particles (lint, etc.) which may impact on the wheel face, are generally removed by the counter flowing airstreams. This feature means that, with respect to accumulation of dry particulate matter, enthalpy wheels require less maintenance than other air handling components.

ETS is comprised of a variety of compounds, particles, gases and vapours including tars, phenols, and other substances22 that condense out of the airstream and coat the surfaces of air handling equipment, including enthalpy wheels. This understanding has implications for system design and product selection as well as operation. All the air handling ductwork and components serving a smoking area are exposed to semi-volatile components of ETS that condense on surfaces. Because they contain so much surface area, filters, coils and heat exchangers can become significant sources of odour as these compounds re-evaporate into the air. Thus enthalpy wheels, like permanent filters and coils, need to be cleaned on a schedule commensurate with the loading in a given environment. In addition, in the case of the enthalpy wheel, a coating of tar and other compounds will inhibit the transfer of water molecules on and off the desiccant coated heat exchange surface, reducing latent effectiveness. In order to recover and maintain latent effectiveness, the enthalpy wheel must be cleaned on a regular basis.

Electron micrograph photos of a suitable enthalpy wheel surface, before and after washing with soap and water, demonstrate that significant loss of desiccant and therefore of latent capacity do no occur

4.7 Advantages

- These wheels are quite compact and can achieve high heat transfer effectiveness.
- Heat wheels have a relatively low air pressure drop, typically 0.4 to 0.7 in. of water.
- Freeze protection is not an issue.
- The cooling or heating equipment size can be reduced in some cases.
- Heat wheels typically have a sensible effectiveness of 50% to 80% and a total effectiveness of 55% to 85%.

4.8 Disadvantages

- Adds to the first cost and to the fan power to overcome its resistance.
- Requires that the two air streams be adjacent to each other and requires that the air streams must be relatively clean and may require filtration.
- Requires a rotating mechanism that requires it be periodically inspected and maintained, as does the cleaning of the fill medium and any filtering of air streams.

4.9 Applications

- Where lower relative humidity is an advantage for comfort or process reasons, the use of an enthalpy wheel pipe can help. An enthalpy wheel used between the warm air entering the cooling coil and the cool air leaving the coil transfers sensible heat to the cold exiting air, thereby reducing or even eliminating the reheat needs. Also the enthalpy wheel heat pre-cools the air before it reaches the cooling coil, increasing the latent capacity and possibly lowering the system cooling energy use.
- Projects that require a large percentage of outdoor air and have the exhaust air duct in close proximity to the intake can increase system efficiency by using a heat wheel to transfer heat in the exhaust to either pre-cool or preheat the incoming air.

4.10 Implimentations

- HOVAL ROTARY HEAT EXCHANGERS provides enthalpy wheels as the solution for the recovery of heat in HVAC systems.
- Pelican PRO green air HP of ENERVENT uses enthalpy wheels as the heart of the system.

V. CASE STUDY

5.1 Hospitality Case Studies

There are numerous hospitality applications of energy recovery ventilation systems in operation today, confirming the utility of these systems in resolving equipment cost and operating cost issues while addressing the ventilation performance and occupant comfort needs of the space. Several notable examples are referenced here:

The Hitching Post food and beverage concession at the Richmond Airport sought to satisfy both smokers and non –smokers in order to maximize return from the airside location convenient to departure gates. Directional airflow, a conservative (higher) ventilation rate of 60 cfm per person (as for smoking lounges), enthalpy recovery and documented commissioning and maintenance procedures combined to produce a space that accommodates both smokers and non-smokers while maintaining humidity control.[5][7]

The dining room and lounge at the Coral Reef Yacht Club in Coconut Grove, Florida used an enthalpy recovery ventilation accessory for a standard rooftop HVAC unit in conjunction with airflow distribution modifications to resolve a smoke and odour problem. Life cycle cost analysis of the system options showed that energy recovery saved 30% of the cost of a conventional system to upgrade the ventilation.

Operating savings were estimated at between $3000 and $4000 annually. The new Sunset Station Hotel and Casino in Las Vegas, Nevada utilizes a central station air handler with 100% outside air and heat recovery to make their smoking permitted casino smell and feel like a non-smoking facility. The system performance is enhanced with highly efficient filtration and plug flow (displacement) ventilation. This system utilizes a plate type heat exchanger due to the dry Las Vegas climate, but an enthalpy wheel would be substituted in a hot humid climate application. A building automation system continuously monitors outside air and pressurization by staging the air handler fans.

VI. COMPARISION WITH OTHER EXISTING SYSTEMS

- Heat pipe should be heavily insulated at central portion to prevent heat transfer while no insulation is necessary in case of the rotary enthalpy wheel.
- Thermo siphons must be mounted such that vapour rises up and liquid flows down to the boiler with no bends in the tubing for liquid to pool. There is no question of alignment (gravity assistance) in case of enthalpy wheels.
- In both heat pipes and thermo siphons additional fans are necessary for proper heat transfer at both the ends.
- Working fluid is required to be maintained on its boiling point at given pressure in both heat pipes and thermo siphons. But here no separate working fluid is used.
- Both above mentioned devices work only on sensible heat. On the other hand enthalpy wheel works on sensible as well as total heat.
- The advantage of both systems over enthalpy rotary wheel is absence of any moving part.

Table: 6.1 Comparison of Enthalpy Wheel with other Existing Systems

Parameter	Enthalpy Wheel	Heat Pipe	Thermo siphon HE
Heat Transfer	Sensible + Total	Sensible	Sensible
Special Working Fluid	Not Required	Required	Required
Insulation	Not Required	Heavily Insulated at Centre	Heavily Insulated at Centre
Gravity Assisted Alignment	Not Required	Not Required	Required
Additional Fans at Working Ends	Not Required	Required	Required
Temp. of Working Fluid	No Requirement	Has to maintained at BP at given Pressure	Has to maintained at BP at given Pressure
Compensation of change in outside temp.	Rotor Speed	Pressure of Working Fluid	Pressure of working fluid
Moving Parts	Present	Absent	Absent

VII. CONCLUSIONS

- Rotary enthalpy wheel technology can be used where there is variation in temperature difference between exhaust and intake air. Because by varying the rotor speed performance of enthalpy wheel can be adjusted as per temperature difference.
- As its working is not affected by gravity, thus it overcomes the problem of alignment faced by thermo siphons.
- Total effectiveness up to 85% makes it best option for heat recovery systems in HVAC applications.

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