Vented air heat recovery in ventilation and conditioning systems based on solid sorbent

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Abstract. Method and equipment for the heat recovery of the air vented from the rooms with application of intermediate heat medium on the base of silica gel are presented. Analytical dependences for calculating the convective heat exchange in the apparatus with fixed layer, boiling bed and two-phase air flow applying granulated sorbents are specified.

1. Introduction

One of the main energy conservation measures in the ventilation and air conditioning systems is the heat recovery of the air vented from the rooms. This is done with the application of heat exchange units (heat recovery units) which are installed in the vent ducts [1].

According to their working principles and constructional features the heat recovery units are divided into recuperative, regenerative ones and units with intermediate heat medium. The most universal is the heat recovery system with the intermediate heat medium (Fig. 1).

Figure 1. The basic diagram of heat recovery with the intermediate heat medium:
1 – heat exchange unit (heat recovery unit) heat extracting;
2 - heat exchange unit (heat recovery unit) exothermic;
3 – the pump for the intermediate heat medium (anti-freeze agent);

Extraction and emission of heat are ensured by the recirculation of liquid – intermediate heat medium (anti-freeze agent) between the heat exchange (heat recovery) units which are mounted in the extract 1 and supply 2 ducts. The heat exchange (heat recovery) units can be placed at significant distances from each other (dozens and hundreds of meters). Recirculation of anti-freeze agent is forced with the pump 3.

Methods of heat recovery integrated into the design of standard apparatus are based on the processes of heat transfer. They do not allow complete recovering of the main component of the air vented from the rooms – latent heat of the water vapor.

It is known [1] that the enthalpy of the of the vented air is determined by the total of components presenting the sensible heat (air + gaseous impurities) and the latent heat of vapor (mainly water vapor):

\[ l = C_\text{pt} + (r + C_\text{at}) \cdot d \cdot \ell 10^3, \]  

where \( l \) – enthalpy of moist air, \( \text{kJ/kg} \); \( C_\text{pt} \) – air specific heat, \( \text{kJ/(kg} \cdot ^\circ\text{C}) \); \( t \) – air temperature, \( ^\circ\text{C} \); \( r \) – latent heat of water vaporization, \( \text{kJ/kg} \); \( C_\text{at} \) – specific thermal capacity of water vapor, \( \text{kJ/(kg} \cdot ^\circ\text{C}) \); \( d \) – moisture content, g/kg of dry air.

Total refluxing of water vapor in the air (total dehumidifying) is possible only when the air is cooled to absolute zero (on \( l-d \) diagram of humid air the curve of total saturation \( q = 100\% \) crosses the enthalpy axis \( I \) under \( t = -273 \, ^\circ\text{C} \) which is practically unapproachable in the given conditions.

In [1] it is shown that the given disadvantage can be eliminated, the heat recovery unit becomes more efficient if its work is based on the sorption processes in the system humid air – solid sorbent. The air vented
from the rooms is passed through a layer of granulated sorbent – a substance with well-developed microstructure which can absorb the water vapor intensively with formation of large amount of heat – adsorption heat (latent heat). The total latent heat of water vapor absorption in the process of capillary condensation is 2930 kJ/kg.

2. Results and discussion

It is known [1, 2] that many sorbents may dry the air flow to zero humidity rate and release almost absolutely dry air into the atmosphere, i.e. recover all latent heat of water vapor and additionally sensible heat in the amount not less than that recovered in modern heat recovery units. Analysis of adsorbents produced by the domestic industry showed that silica gel is most efficient for adsorbing water vapor from the air flow. It has the following advantages: high selective adsorptive power for the water vapor and high hydrophilic properties; low reactivation temperature (110...200 °C) and, as a result, lower power consumption than that associated with reactivation of other industrial sorbents; possibility of synthesizing silica gels with a wide range of specified structural characteristics through the use of rather simple techniques; low cost-price under the large-scale industrial production; high mechanical strength with respect to abrasion and compression; incom bustibility.

To improve the thermo technical efficiency in the recovery system with the intermediate heat medium it is suggested to equip the air-cooling unit with the functions of absorber and heat exchange unit (let us call it heat exchanger-absorber). For total extraction of the water vapor heat as well as for extraction of the sensible heat of the dried vented air the layer of the adsorbent is placed in the tube side of the shell-and-tube heat exchanger and the intermediate heat medium circulates in the intertubular space. The intermediate heat medium extracts the heat from the adsorbent layer, becomes warmer and transfers it via the exothermic heat exchanger to the outside (incoming) air.

We suggest using 20%...30% water solution of ethylene glycol and propylene glycol having low freezing temperatures [1].

Standard constructions – pipe and flange contact apparatus which working principle is based on filtrating the gas through the layer of fixed granulated material (catalyst) – are used for the catalytical purification of gases [2].

We suggest completing the activation (reactivation) of adsorbent according to the method of replacing desorption method, i.e. by applying the element of heatless process of desorption which mechanism is considered in [1].

To ensure the process continuity two heat exchangers-absorbers are required: one works in the mode of recovering latent and sensible air heat, another works in the mode of sorbent activation (reactivation).

Through the layer of silica gel to be activated we filter the vented, completely dried air obtained in the nearby heat extracting heat exchanger before releasing it into the atmosphere.

Due to the large difference between the partial pressures of water vapor in the pore volume of the adsorbent and the air flow being blown through it the molecules of water are intensively diffused into the air flow.

As opposed to the mode of heatless reactivation of adsorbent all dried air flow will be used for blowing as dried air is not a marketable product in the given process and does not contain adsorption heat any more.

According to the equation [1]

\[ G_d = \frac{G_a P_d}{P_a} \]  

under the equal flow rate of the air flow at adsorption and desorption stages \( G_a = G_d \), the pressures of the air flows at the given stages will be equal in value \( P_a = P_d \) and approximate to the atmospheric pressure.

The principle diagram of the heat recovery of the air vented from the rooms on the base of a sorbent is given in Fig. 2, the principle diagram of heat exchanger-absorber is given in Fig. 3.

**Figure 2.** The diagram of heat recovery with the intermediate heat medium:
1, 2 – heat exchangers-absorbers (heat recovery units); 3 – heat exchanger-air heater for the outside air; 4 – the pump; 5 – expansion tank; 6 – air-supply ventilator;
7 – extraction ventilator;
8,9,10,11,12,13,14,15 – interception valves;
16, 17 – air valves;
18 – gate valve

Figure 3. Diagram of heat exchanger-adsorber:
1 – case; 2 – tube sheet;
3 – tubular member with silica gel;
4 - covers; 5,6 – pipe pieces for the air;
7,8 – pipe pieces for the intermediate heat medium

Heat recovery of the vented air with application of the intermediate heat medium includes the following stages (modes).

The stage of water vapor adsorption and extraction of the latent and sensible heat of the vented air.

The air vented from the rooms is sent to the heat exchanger-adsorber 1 with the help of ventilators 6, 7. When it happens, valves 8, 9, 14, 15 are open, valves 10, 11, 12, 13 are closed.

In the heat exchanger-adsorber the air flow passes through the tube side filled with the layer of adsorbent – silica gel, dries due to water vapor sorption to the completely dry state (Fig. 2, Fig. 3). As this process goes on the heat of adsorption is emitted. Then the air is cooled with extraction of adsorption heat and partly of sensible heat with the help of the intermediate heat medium supplied into the pipe side of the apparatus by the pump 4 (Fig. 2). At this time air valve 16 is open, air valve 17 is closed.

The heated intermediate heat medium is transferred to the surface heat exchanger-air heater 3 and transmits the heat up to the cold outside air due to the process of heat conduction and then, being cooled down, is again supplied into the pipe side of adsorber-air cooler 1 to cool the air flow (Fig. 2, 3) and so on.

Stage of adsorbent activation. Ventilator 7 supplies the air dried to completely dry state and the cooled air from the heat exchanger-adsorber 1 to adsorber-air cooler 2 which is at the stage of adsorbent activation (Fig. 2). The air moves from the bottom upwards through the fixed layer of granulated adsorbent in the pipe side and causes desorption of water molecules into the air flow due to the difference of the partial pressures of the water vapor at the surface of silica gel capillary and in the air. The humidified air flow from apparatus 2 is released into the atmosphere through valve 15.

Air blowing (adsorbent activation) through the layer of adsorbent is stopped when the minimal residual humidity of silica gel is achieved. This can be monitored by measuring the moisture content of the released air. After that valves 14, 15 are closed and the gate valve 18 is opened and the dried air from the heat exchanger-adsorber 1 is released into the atmosphere by-passing heat exchanger 2.

After the silica gel in adsorber-air cooler achieves its equilibrium state (the duration of adsorption or the moisture content of the released air may serve as indirect indicators) the apparatus is switched to the stage of adsorbent activation and the air vented from the room is supplied to the heat exchanger-adsorber 2 for drying and cooling. To do this, valves 8, 9, 14, 15 must be closed and valves 12, 13, 10, 11 must be open. Air valve 17 must also be opened, while air valve 16 on the line of intermediate heat medium must be closed.

In the given cycle the air removed from the room moves through the layer of adsorbent from the bottom upwards in the heat exchanger-adsorber 2 driven by ventilators 6, 7. As it happens the air is dried emitting the heat of adsorption and also cooled due to the action of intermediate heat medium supplied into the shell side of the given apparatus.

Circulation of intermediate heat medium through apparatus 2 is ensured by pump 4 through the
opened valve 17. The intermediate heat medium transports the heat extracted from the dried air to the heat exchanger-air heater 3 where the intermediate heat medium transfers the heat to the outside air and goes back for heating to the shell side of heat exchanger-adsorber 2 and so on.

Completely dried and cooled air flow from apparatus 2 is supplied to heat exchanger-adsorber 1 for adsorbent activation. Ventilator 7 supplies this air through valve 10 into the pipe side of heat exchanger-adsorber 1 where it encourages desorbing water molecules from the layer of adsorbent into the air. The humidified air from the top of the adsorber is released into the atmosphere through the opened valve 11 by ventilator 7.

To intensify the process of desorption it is possible to additionally install a vacuum pump to reduce the pressure in the heat exchanger-adsorber which is in the activation stage. The vacuum pump can be mounted in the general air line after valves 11 and 15 (the pump is not shown in Fig. 2).

This way, alternatively, one after another, the heat exchangers-adsorbers are in the stages of either adsorption or desorption ensuring the continuity of heat extraction and recovery from the air vented from the room.

The apparatus with the “boiling bed” of grainy adsorbent and cyclone-type apparatus can be also used as heat exchange-adsorber [1, 2]. The principle diagrams of the given apparatus are presented in Fig. 4.

Changing the granular adsorbent from the fixed layer into the moving bed: into the “boiling bed” (Fig. 4a), into the through two-phase flow (Fig. 4b) – intensifies the heat and mass transfer [2]. At the same time, the linear dimensions of equipment can be significantly reduced and less production area will be required for the system of heat recovery.

To make the structural analysis of heat exchangers-adsorbers we have developed the methodology basing on the application of the number of transfer units. The number of transfer units is established with the help of the modified I-d-diagram of moist air [3].

To estimate the convective heat exchange in the system air flow – wall we can use the following analytic dependences [2]:

- in the apparatus with the fixed blown through grainy layer (Fig. 3)
  \[ N_u = 0.31 \text{Re}^{0.75} [(1 - \varepsilon)^{0.5} / \varepsilon] \]  
  \[ N_u = 0.1 \text{Re}^{0.8} [(1 - \varepsilon)^{0.8} / \varepsilon] \]  
  \[ N_u_{\text{max}} = 0.86 \text{Arch}^{0.2} \]  

- in the apparatus with the “boiling bed” (Fig. 4a)  
  \[ N_u = 0.3 \text{Re}^{0.51} \text{Re}_p^{0.63} \mu^{-0.11} \]  

where \( \text{Re} \) – Reynolds number for the single-phase flow; \( \varepsilon \) – porosity; \( \text{Re}_p \) – Reynolds number calculated using the weighing rate of the air flow \( \mu \) – weight concentration of sorbent particles in the air flow, kg/kg; \( \text{Arch} \) – Archimedes criterion.

Equation (3) is applicable under \( \text{Re} = 1.5...57 \); equation (4) – under \( \text{Re} = 57...1500 \); equation (6) –
under \( \text{Re} = 14000...36500; \text{Re}_B = 3.6...5.3; \mu = (0.25...1.79) \text{ kg/kg} \).

In paper [1] it is shown that recovered heat gain \( \Delta Q, \text{kW} \) in the suggested method in comparison to the traditional ones equals:

\[
\Delta Q = 2.93 \cdot \dot{G} \cdot \dot{d}_w
\]

(7)

where \( \dot{G}, \dot{d}_w \) accordingly, consumption, kg/h, moisture content of the removed air, g/kg of dried air.

3. Conclusion

An efficient method of the heat recovery of the vented air with application of intermediate heat medium on the base of solid sorbent was developed. The advantage of the method is the opportunity of significant increase of the amount of the recovered heat from the air vented from the rooms due to complete extraction of the latent heat of water vapour contained in this air at the initial stage.

Разработан эффективный способ утилизации теплоты удаляемого воздуха с промежуточным теплоносителем на основе твердого сорбента. Достоинством способа является возможность значительного увеличения количества утилизируемой теплоты от удаляемого воздуха из помещения за счет полного отбора скрытой теплоты водяных паров, содержащихся в нем на начальной стадии.

References

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