SPRINKLED HEAT EXCHANGERS OPERATING AT ATMOSPHERIC PRESSURE

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The paper presents a state of the art review of fundamental research of heat transfer process in liquid sprinkled heat exchangers placed in atmospheric and also in vacuum chamber. It compares the structure of atmospheric and vacuum stand. In this article, the temperature falls are experimentally investigated in the condensation and boiling regimes on the experimental tube bundles. The results were obtained by analysis of thermograms of the tube bundles during operation period.

Keywords: *heat exchanger, atmospheric pressure*

1. Introduction

Ages ago people started to utilise cooling along with heat to preserve food. An example of that is The Plzeňský Prazdroj Company which used to harvest ice on ponds and then stored it in the cellars to keep the beer cool. Since then many years passed and today the modern cooling technologies such as absorption cycle are used. This company launched an absorption cycle project in 2003 and delivers cooling capacity of 1.5 MW [2].

Another, and in fact more widespread, cooling technology method is the application of the vapour compression refrigeration cycle. If compared to the absorption cooling cycle, the vapour compression refrigeration cycle is more compact, weighs and costs less and delivers the same cooling capacity. The main cons are that it suffers from a shorter life span and is noisier. The absorption cycle's only rotating component is in a pump and thus there are no special requirements. Although the absorption cycle's initial costs are higher, its operation costs are lower. Electric energy consumption's price is about one fifth or one tenth of the compression cycle's price. Considering the initial costs and price of electrical energy, the payback period is approximately the same for both systems. For a closer description and both cycles comparison is reader referred to [1].

2. Atmospheric stand

One of the key components of an absorption cycle is a heat exchanger which optimises the heat transfer process. The first produced experimental device operates at the atmospheric pressure and is concerned with various spacing and surface treatments of the heat exchanger tubes.

A tube bundle (2) featured in Figure 1, is mounted to a frame (1). It consists of up to 20 vertically aligned tubes variously arranged and with various inclinations. The tube spacing can range from 15 to 35 mm and 5 mm spacing step is possible. The flow rate of cooling

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loop (tube bundle) can reach 310 l/h. Sprinkling water is pumped above the tube bundle through a distribution tube which has holes ⌀1.5 mm. Each hole is distanced 10 mm from the previous one. The tube bundle itself is composed of ⌀12 mm copper tubes. We tested: smooth, sandblasted, and grooved tubes.

Four thermocouples, which measure temperatures at the sprinkling water input and output, were installed in the experimental device. Two ways to measure the flow rate are used. The instantaneous flow rate is measured by a flow meter (3) and the total flow by a water meter (4). A flow-through heater (5) heats up water which is sprinkled over the tube bundle; the water is then collected in a tray (6). The water used for sprinkling is regular water from a water-supply network.

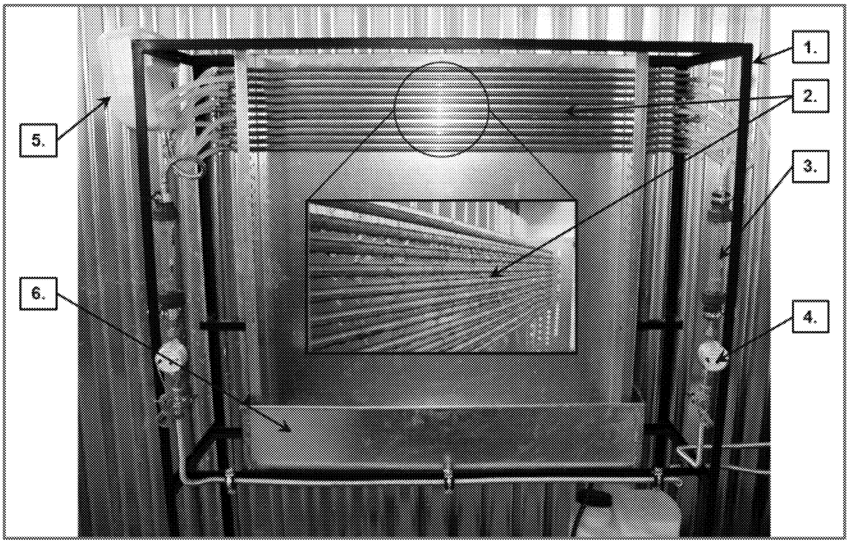

Fig.1: The atmospheric heat exchanger stand

The volume flow rate is determined based on the difference in between the both flow meter read outs at the beginning and end of the measurement. The procedure applies to all tested flow rates, tube spacing as well as tube surface treatments.

The heat loss of the watered side of the heat exchanger based on the temperature difference encountered with the lowest flow rate for various tube spacing and the cooling loop being shut off was determined. At the maximum flow rate, i.e. 300 l/h, the temperature difference of the sparkling water entering and leaving the tube bundle is zero, which was proved by the measurement. The temperature differences resulting from the flow rates in between minimum and maximum were obtained by means of linear interpolation. The heat loss at the refrigerant liquid side was determined employing the temperature difference obtained when the sprinkling loop was closed off. Along with the heat loss, the total amount of heat rejected and absorbed at various flow rates was acquired. Subtracting the total heat absorbed from the rejected one gives the actual amount of heat transferred between the sparkling water and refrigerant liquid. The investigated heat transfer coefficient was then calculated applying Newton's cooling law and Fourier's law of heat conduction.

3. Vacuum stand

The heat transfer research of a water sparkled tube bundle at atmospheric conditions is closely followed by development of the tube bundle situated inside a chamber where the pressure is kept below that of atmospheric by means of an ejector vacuum pump. In this way, both boiling and condensation over the tube bundle can be simulated using the chamber (Figure 2).

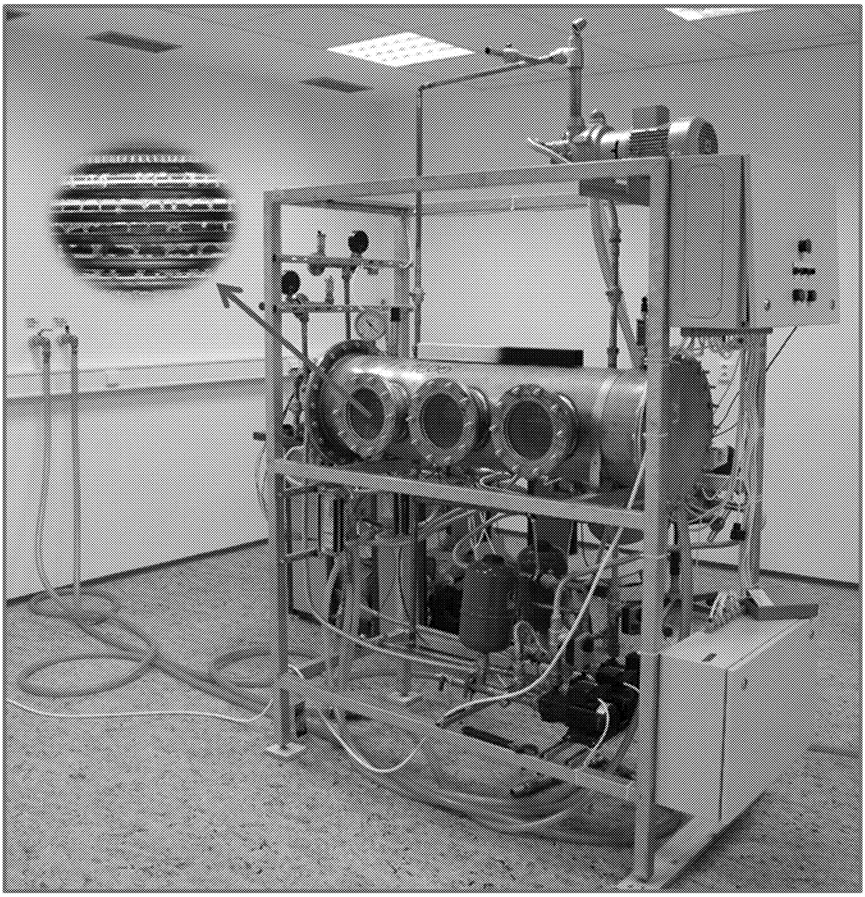

Fig.2: The vacuum heat exchanger stand

The vacuum stand chamber is essentially a cylindrical vessel 1.2 m in length fitted with three peep holes in which the tube bundle of 940 mm in length is located. Three closed loops are connected to the chamber. The ones on sides are designed to withstand 1 MPa of gauge pressure and supply the chamber with heated or chilled liquid. The third, central loop feeds in the sparkling water. Each loop includes a pump, a governing valve, a flow meter and a plate heat exchanger. The plate heat exchanger can be either connected to a hot water boiler to provide heat or to chilled water source when cooling is required. The gauge pressure loops are also fitted with expansion vessels and safety valves.

Thermal states of respective loops are measured with the use of thermocouples located at the inputs and outputs to the chamber. In order to detect the temperature gradient across the tube bundle, temperature is measured inside each loop using two thermocouples. The metal sheet enframing the tube bundle contains a set of holes of various spacing to allow for different tubes arrangement. Tubes of 12 mm in diameter make up the tube bundle. The distribution tube has 1 mm holes in it 9.2 mm apart along 940 mm of the tube.

The vacuum pressure is taken with three vacuum gauges; the first one (mercury type) serves for visual check-up. The second one is a digital one which covers all required vacuum range, though of low accuracy at very low vacuum levels. High accuracy of low vacuum pressure measurement – ranging from 0 Pa to 20 kPa – is attainable with the use of the third meter.

Regarding the flow rate measurement, it is performed employing Flomag 3 000 electromagnetic flow rate meter. Each loop is fitted with such a meter.

4. Results comparison

In the picture nr. 3 is a snapshot taken by thermo vision camera Flir 660 during the sprinkling of skew tubes in the atmospheric stand. The tubes are inclined 1.8° against the direction of sprinkling fluid. The snapshot is taken during the flow rate of 200 l/min and tube spacing of 30 mm. The tubes are positioned in one vertical row. It is apparent, that for this fin spacing is the flow rate very small, because the tubes on the right side are not sprinkled (inflow of the sprinkling fluid is from the left side) and heated (at the bottom part because the air temperature was higher than the temperature of heated agent; it means cca. 20 °C) and in the top part cooled by the air. The thermocouples are positioned at the loops starts and ends and thus it is not possible to determine the boundaries of positive and negative influence of ambient air.

Fig.3: Sprinkling in atmospheric stand

The evaluation of 6 second sequences taken by thermo vision camera Flir 660 with frequency of 30 Hz on the vacuum stand in the middle slit can be seen in the picture 4 and 5. In the picture 4 is a fluid which was heated inside the tubes from 25.9 °C up to 30 °C (Measured for 2 minutes with measurement frequency of 0.704 Hz by thermocouples on the inlet, respective on the outlet from the loop. This sequence was recorded in this progress.). The average flow rate was 10.6 l/min. The sprinkling fluid had an average inlet temperature

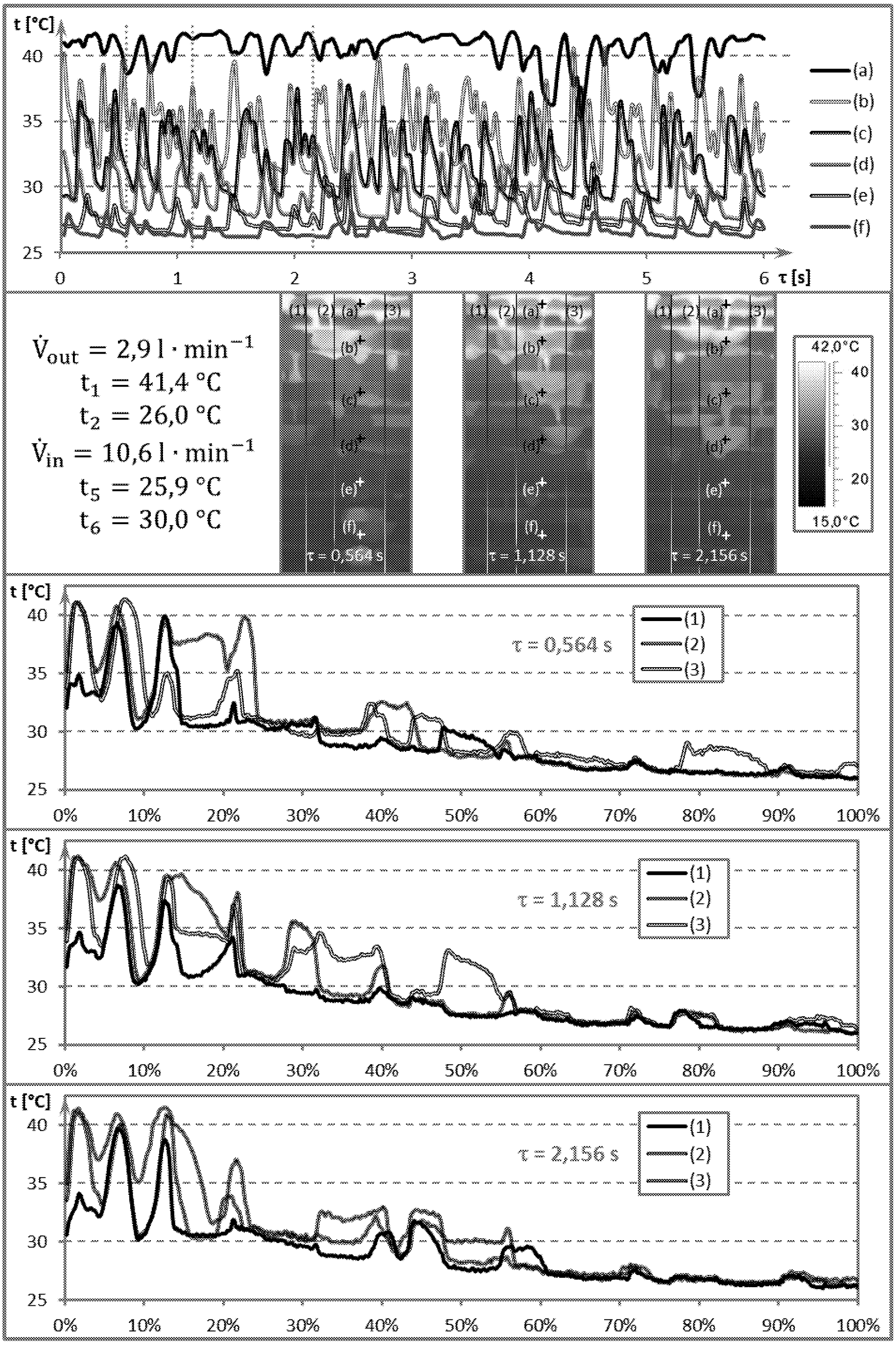

Fig.4: The thermo vision record evaluation of sprinkling on the vacuum stand (condensing regime)

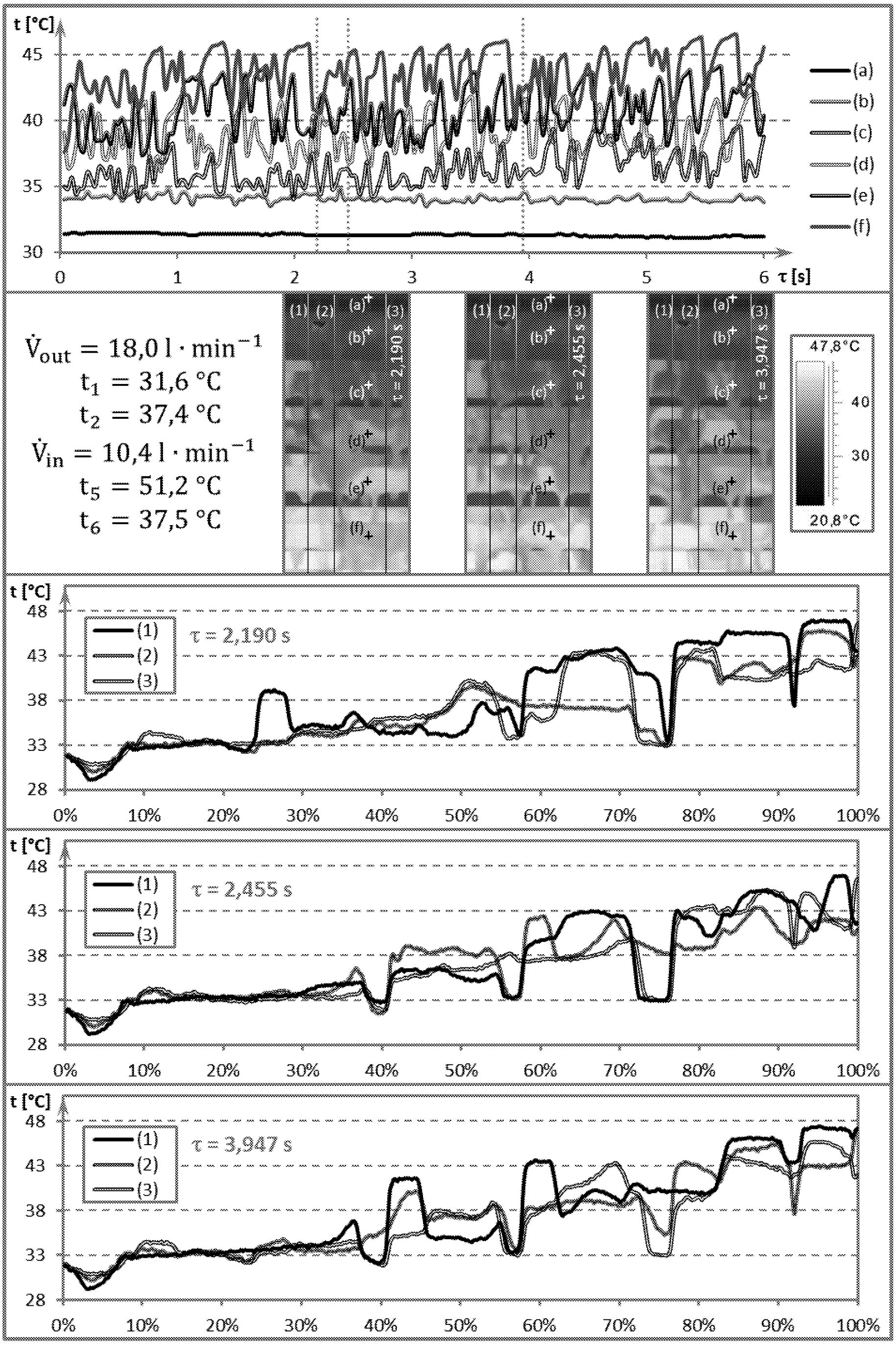

Fig.5: The thermo vision record evaluation of sprinkling on the vacuum sand (boiling regime)

41.4 °C and the outlet temperature 26 °C. The average flow rate was 2.9 l/min. In the upper part of the picture can be seen the temperature progress scanned in six points (marked by letters from 'a' to 'f'). The first point is located in an area of sprinkling water distributor tube outlet. The rest of the points is located in the frontal area of the tube bundle. All the points are highlighted on the pictures, which were taken from the sequence record located under the graph. In those pictures are also three lines (marked from '1' to '3') in which is the temperature measured in the entire length. This is the length of the x-axis in graphs under the pictures, on which is this temperature for given time depicted. In the picture 5 is the same arrangement, but the fluid was cooled inside the tube from 51.1 °C to 37.5 °C. The fluid flow rate was 10.4 l/min. The sprinkling fluid had at the distributor tube inlet the temperature of 31.6 °C and at the outlet of the container (in front of the pump) 37.4 °C. The flow rate was 18 l/min.

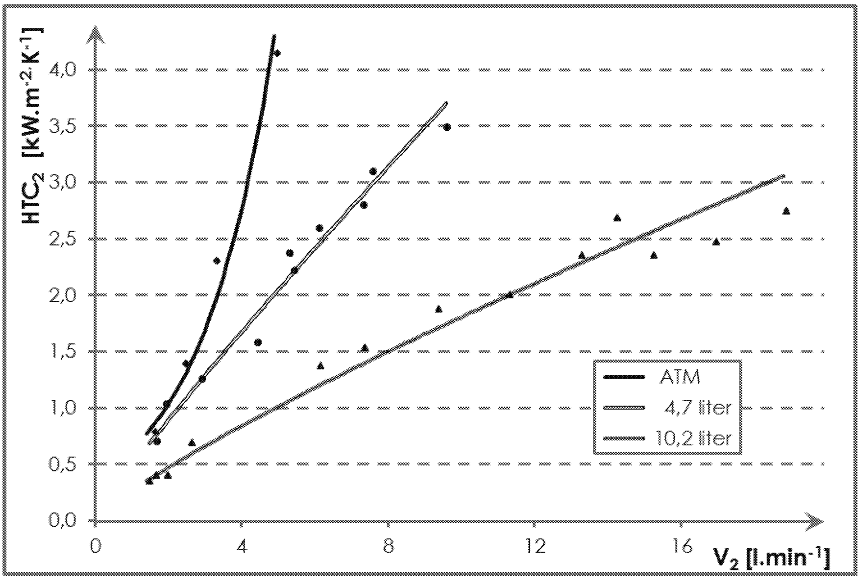

Fig.6: Heat transfer coefficient in condensing regime

The comparison of researched heat transfer coefficients at the atmospheric pressure in condensing regime is shown in the picture nr. 6. The tubes had spacing of 25 mm and were hot water sprinkled. Inside the tubes was kept a steady coolant flow (For the atmospheric stand – the curve was signed as ATM – was kept a steady flow of 2.5 l/min. For the vacuum stand were kept the flow rates of 4.7 and 10.2 l/min.).

The boiling regime at the atmospheric pressure was measured only on vacuum stand and the results are featured in the picture nr. 7. Hot water circulated inside the tubes at the constant flow of 4.7 l/min and 10.3 l/min and was cooled by the sprinkling fluid.

5. Conclusion

The contribution has outlined the development in the research of absorption cycles at the Brno University of Technology; namely, in the field of heat transfer connected with sprinkled tube bundles. A chart of preliminary data as obtained by employing both atmospheric and vacuum stand experimental data is provided as well. The values of the heat transfer

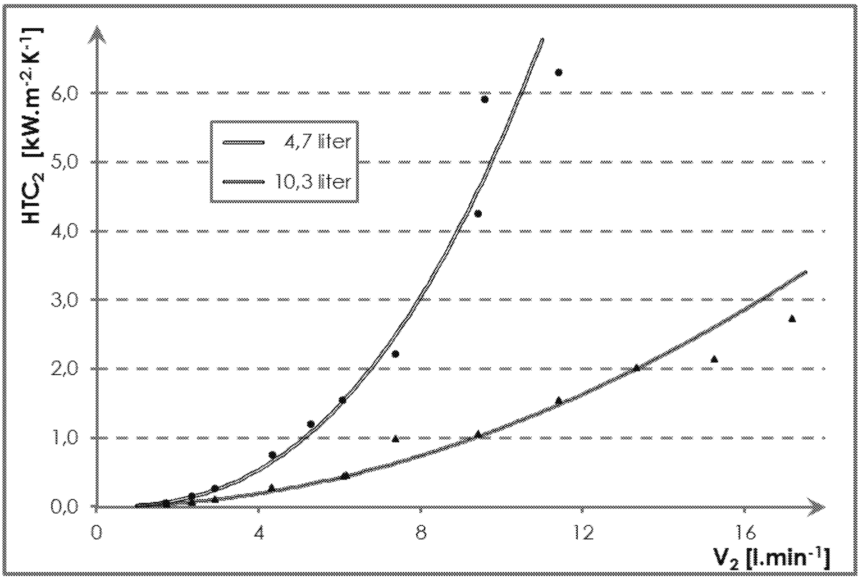

Fig.7: Heat transfer coefficients in evaporating regime

coefficient were approximated by the exponential curve fitting method, which seems to be the best match to the contemporary theoretic background. When comparing the curves obtained at the atmospheric pressure condition, though the pressure at the vacuum stand was 97.7 kPa, there is a discrepancy among the individual values, but it corresponds to the measurement methods employed; the curve trends were confirmed. The temperature gradient along with the difference in the diameters of sparkling holes may be other factors influencing the measured values at the atmospheric pressure condition; the latter affects droplets formation and consequently the liquid film over the outer surface of the tubes. These will be subject to further investigation.

Acknowledgement

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