Improvement of the condensation efficiency of the condensation hood

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Abstract. Condensation hoods are currently widely used in modern gastronomy. They condense the steam produced by the combi-steamer during the food preparation process. In this paper, some improvements implemented to the design of the hood heat exchanger are described. Experimental and computational analysis allow to determine the consequences of those modifications in terms of condensation efficiency as well as their impact on production cost. Results of the measurements are in good agreement with results of simulations carried out using in-house CFD model.

1. Introduction

Combi-steamers are industrial devices which are commonly used in contemporary gastronomy. They can work in various semi-automated cooking modes like steam, hot air, and a combination of both allowing roasting, baking, steaming, defrosting, reheating, etc. guaranteeing appropriate quality of food. Thanks to this versatility, combi-steamers have become an integral part of kitchen equipment [2].

Combi-steamers, however, guaranteeing the appropriate internal environment, at the same time produce a significant rate of steam and odour being released from the oven directly to the kitchen space. Hence, staff may suffer from too high air humidity and quality of the meals which are being prepared to be served can partially be spoiled [1]. Remedy for such a situation is an application of stationary steam vents or more frequently so-called condensation hoods. Typically, these condensation hoods are maintained on the top of the combi-steamers. The typical solution is shown in Fig.1(a) while Fig.1(b) presents an operation idea of the original condensation hood.

Condensation hood generally captures steam produced by the combi-steamers and condenses it. The condensate is then returned to the oven by gravitational force or goes directly to a drain. In the ideal case, all steam produced by the combi-steamer should be condensed and returned to the oven. This is why the condensation hoods should be as efficient as possible. Designing such devices requires advanced engineering tools, such as computational fluid dynamics (CFD). They allow to analyse of the unit processes as well as allow for a preliminary diagnosis of the prototype before it is constructed and installed, cf. [3].

Despite the fact that this type of device has well-established position on the market, the number of comprehensive scientific publications discussing its design and operation is fairly
limited. Particularly, information on the condensation efficiency of the hood is not easily available. To the authors’ best knowledge, only recently one type of condensation hood, frequently used in gastronomy, has been experimentally tested in various working conditions [4]. Those measurement results allowed the authors to build and partially validate the in-house computational model of this hood [5] but also to propose some design modifications. Detailed analysis of the heat and mass transfer together with water steam condensation processes resulted in a completely new design of the hood [6]. This analysis also provided the basis for the development of potential improvements.

The position of a given industrial condensation hood on the market depends mainly on its condensation efficiency as well as on the production cost. From that point of view, the most important part of the condensation hood is certainly a heat exchanger where steam outflowing from the combi-steamer is cooled and then condensed. In the original design this condensation takes place on the external side of the internally finned pipes. Manufacturing of this heat exchanger is the most time consuming production operation and that is also the most expensive part of the hood. In this paper, some improvements of both condensation efficiency as well as on production cost are discussed. They are results of gradual modification of the heat exchanger and are proved by computational modelling and measurements as well.

2. Gradual modification of the heat exchanger of the condensation hood

Fig. 2 shows isometric view of its interior. The device is equipped with a fan that sucks humid air from the environment through the inlet and pushes it through the heat exchanger located inside, where steam condensation occurs. The heat exchanger of the condensation hood is equipped.
with several dozens of internally finned pipes organised in two bundles. The steam is mixed with the air at the fan inlet. Humid air pulled through the appliance is finally released back to the environment through the air outlet.

The condensation efficiency \( \eta \) of the condensation hood is defined as the ratio of the mass flow rate of the water steam condensed \( \dot{m}_{\text{cond}} \) and the mass flow rate of the water steam generated by the combi-steamer and flowing into the condensation hood \( \dot{m}_{\text{steam}} \). Analysing in detail the results of the condensation hood laboratory tests showed that the condensation efficiency in normal working conditions is equal to 91.6%. This value is in good agreement with the value obtained using the in-house CFD computational model developed for this original construction [4]. The dead zone of the heat exchanger, where no condensation occurs, has been found in many computer simulations. Investigating this effect, a new design that forces uniform flow through pipe bundles has been proposed. As result, the number of pipes can be significantly reduced (i.e., even by 25%) without a noticeable drop in condensation efficiency. The condensation efficiency of the redesigned construction has been confirmed by the experiments conducted using a prototype device manufactured by the condensation hood producer. Although such a modification does not improve the condensation efficiency, but it reduces considerably the production cost.

Figure 3 presents an isometric view of the redesigned construction. Pipe bundles of the heat exchanger were merged and moved to one side of the hood. Instead of flowing into the distribution chamber (space between the bundles where the coolant air is pulled by the fan) and then into the pipes, now the air flows directly into the space between pipes. Air flow is directed by the flow guide and one baffle positioned centrally. The total heat transfer surface increased substantially using external fins that are much thinner and more numerous than their previous counterparts. This solution allowed for reduction in the number of internally finned pipes from 48 to only 5 U-shaped externally finned horizontal pipes (cf. Figure 4). In the inlet side, the
steam is mixed with the air at the fan inlet. Humid air pulled through the appliance is finally released back to the environment through the air outlet.

**Figure 3.** Redesigned construction; 1 – fan outlet (coolant air inlet); 2 – air outlet; 3 – steam vents.

**Figure 4.** Externally finned pipes of the heat exchanger, vents and flow guide.

The pipes and both headers are slightly inclined towards the steam inlets, so the condensate
is removed from the exchanger by the gravitational force back to the oven. The steam condenses inside the pipes while flowing through them. Remaining, not condensed, steam leaves the pipes and is mixed with the air (i.e., diluted) in the fan, and finally transported to the environment.

Prototype of the condensation hood equipped with the redesigned heat exchanger has been examined in two situations. The first one refers to the typical working conditions in which the thermal power was 3.4 kW, while the second one imitates the extreme mass flow rate of the steam entering the hood. In this case, the thermal power was 15 kW. To be sure, what is the mass flow rate of the steam, in both cases the steam is supplied by a laboratory steam generator. Measured condensation efficiencies have also been determined using in-house CFD models. Results are collected in Table 1. It should be added that the relative humidity of the coolant air ranged from 30 to 40% and the temperature varied from 25 °C to over 30 °C.

Table 1. Experimental (Exp.) and calculated (Cal) results (including condensation efficiency) of the tested hood.

| Test | Result type | \( t_{\text{air, in}} \) °C | \( t_{\text{air, out}} \) °C | \( m_{\text{air, in}} \) kg/s | \( m_{\text{steam}} \) g/s | \( m_{\text{cond}} \) g/s | \( \eta \) % |
|------|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Test A | Exp. | 24.5 | 41.7 | 0.2 | 1.32 | 1.29 | 97.9 |
| Test A | Cal. | 24.5 | 40.0 | 0.2 | 1.32 | 1.32 | 100.0 |
| Test B | Exp. | 31.4 | 75.2 | 0.2 | 5.55 | 3.56 | 64.2 |
| Test B | Cal. | 31.4 | 76.1 | 0.2 | 5.55 | 3.67 | 66.1 |

3. Concluding remarks
This paper describes the modifications carried out for the steam-air heat exchanger which is the most important element of the condensation hood. Its main aim is to condense the steam generated by the combi-steamer during the food preparation process.

In typical working conditions, the prototype condensation hood, that is equipped with the redesigned heat exchanger, demonstrates the condensation efficiency slightly above efficiency of the original construction. The condensation efficiency predicted by the computational model has been confirmed by the measured values.

References
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