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POSSIBILITIES OF VAPOUR CONDENSATION AND HEAT ACCUMULATION SYSTEMS FOR LOCA ACCIDENTS IN NUCLEAR POWER PLANTS

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Abstract: The condensation process of vapour described in this article is generally studied and defined according to classical and experimental approaches. These general approaches have explored vapour condensation by different methods in very specific conditions and physical modifications. Mathematical formulations and practical conclusions from these approaches directly resulting in an applicable vapour condensation process have been theoretically examined for heat accumulation systems used in nuclear power plants. The heat accumulations systems are represented by ice condensers which are employed for vapour condensations during LOCA accidents. Generated vapour from the pressurized water in the primary circuit causes pressure increase in containment. The dangerous pressure peak is reduced by the vapour condensation on the ice layer. The disadvantageous features of the ice as a heat accumulating material can be solved by its replacing. The replacement is in view of materials providing the phase change within a specific temperature range close to the operating conditions of the nuclear power plant. The vapour condensation at the system filled by the replacing material is studied in different forms while accepting specific conditions of the given experimental system generally described. The experimental system offers the same possibility of the vapour condensation, however, the conditions impacting condensation effectiveness are mentioned and compared. The fundamental settings of the theoretically designed system are accordance to the conditions caused by the LOCA accident. The given comparison of the heat accumulation system providing the vapour condensation is mostly focused on the vapour steam direction, phase change temperature and heat transfer process.
Keywords: vapour, condensation process, nuclear power plants, LOCA accidents

1. INTRODUCTION

The nuclear safety is a specific topic of the nuclear power presently. The nuclear disaster in the Japan nuclear power plant Fukushima Daiichi has reminded the importance of proofed and reliable systems used in the active or passive mode for application in case of serious nuclear accident. Preferentially the passive systems not demanding active human or operating interaction for its functioning are currently considered as solution partly for the power plants under operation and mostly for the new installations represented by different projects (AP1000 or VVER-1200 as the GEN III+ reactor) [1].

Ice condensers applied in nuclear power plants in Japan, Finland and the U.S. represent one of the important passive systems generally operated. Their function is fundamental for the loss-of-coolant accidents (LOCA), which occurs when the coolant from primary circuit in the form of pressurized water is suddenly after any disruption released into the containment empty volume (if the containment is applied) as vapour. The increasing pressure inside of the containment may not overpass the safety limits and must be effectively reduced by vapour passing through the ice condenser. The ice condenser is designed for melting of contained ice when the produced vapour flows through it and condense. The ice phase change from solid to liquid state provides a storage capacity for the released heat and also decrease of the pressure from generated vapour in the containment. The possible ice replacement, as a heat storage material, by another phase changing material (PCM) with the phase change closer to operational temperature within the containment would definitely reduce operating costs (necessary power for keeping the ice material solid in the warmer place) and simplify the reactor system required maintenance [2].

The ice replacement by PCM requires not only the sufficient material selection (to keep certain criteria of the nuclear safety and operational demands), but also the design of a novel heat exchanger providing the contact between the condensing vapour and melting material.

2. THE EXPERIMENTAL CONDENSER

For the purposes of the PCM replacement instead of ice and its validation an experimental condenser installation is necessary to be designed and operated in the mode of vapour condensation within specific conditions as much as comparable to the situation in the nuclear power plant. The ice melting in the situation of vapour condensation occurs directly without any surface contact component. The vapour flux becomes water and subsequently is mixed with melting ice. The arisen liquefied water is forced by gravitation to flow down under the ice condenser. In case of the PCM application the direct contact between the condensing vapour and melting material is not realizable. The possible PCM material (according to the final conclusion about the choice of PCM it will be paraffin for the experimental purposes) has very different chemical properties comparing to the water and is not advisable to mix them together. Thus the condensing process will occur within the tube system (see in Figure 1). The vapour flows and condenses inside of tubes while the PCM material becomes melted in a space defined by the external cylinder. The total amount of PCM is equal to the volume given by the external cylinder reduced by the volume of tubes (the assembly of tubes represents a conventional heat exchanger). Direction of the vapour can be switched without restraint upward or downward according to the experimental settings.

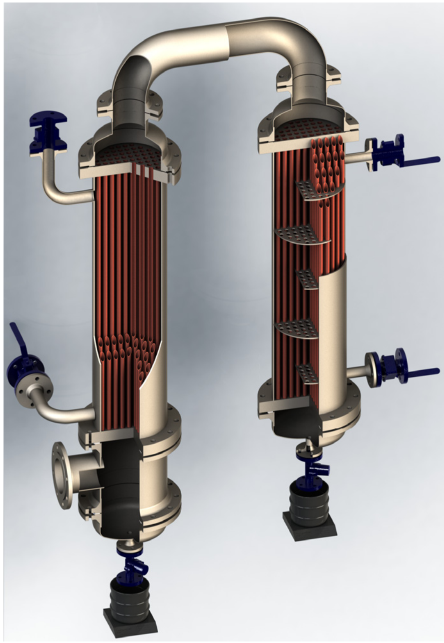

Figure 1. The experimental condenser: the left part of the heat exchanger is filled by tested PCM, the right part of the installation is cooled by water

Similarly to the ice and its melting temperature the PCM material provides the boundary condition of the constant temperature when becomes liquefied. The melting temperature can be chose especially for paraffin within very wide range of temperatures. The melting temperature of PCM should not be lower then 50 °C to keep it in the solid phase for the conditions prevalent in the operated nuclear power plant inside the containment. Lower melting temperature would causes that the PCM can be in liquid phase in the situation of any accident. The effect of the heat accumulation in the form of latent heat then would be negligible.

The functional facility, containing also the condenser as a part, must be connected by thermocouples to an evaluating system. Beside the condenser the facility requires other supporting systems such as a steam generator, controlling and operating valves, additional condensers and system of connecting tubes (see in Figure 2).

3. FUNDAMENTALS OF CONDENSATION

The condensation process is generally well known and described by different theoretical or practical approaches. Considering the number of articles and manuscripts dealing with condensation it is necessary to define basic statements about the experimental facility and practical recommendations.

The condensation process during the experiment with application of PCM in the form of paraffin will provide the theoretical boundary condition by the melting temperature which defines the wall temperature at the inner surface of the thin tubes. Respectively the boundary condition of the constant temperature for condensation is not completely implemented. The beginning temperature of the PCM material will be lower then the melting temperature. For the theoretical approach is considered that the melting temperature will be reached quickly when the vapour flows through the experimental facility. Also is assumed the vapour is saturated for given pressure. These parameters are given by the blowdown function and can be expected within the containment after the LOCA accident [3]. The important part of the calculations is the type of vapour flow. There are two basic types of the flow – countercurrent or cocurrent comparing to the flow of condensing film [4].

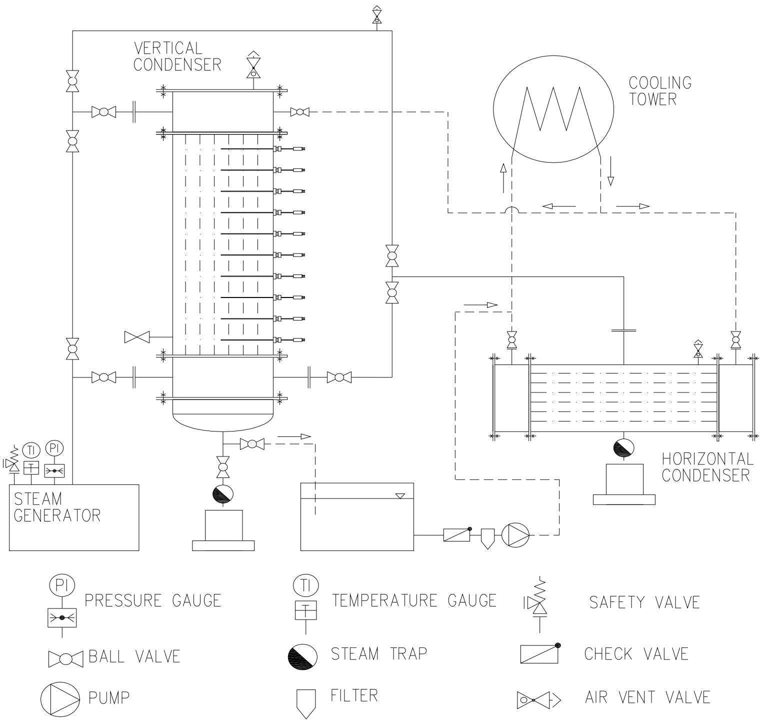

Figure 2. The general drawing of an experimental facility

According to the general equations of the film condensation thickness and heat transfer coefficient the following values can be expected – see Figure 3 and Figure 4.

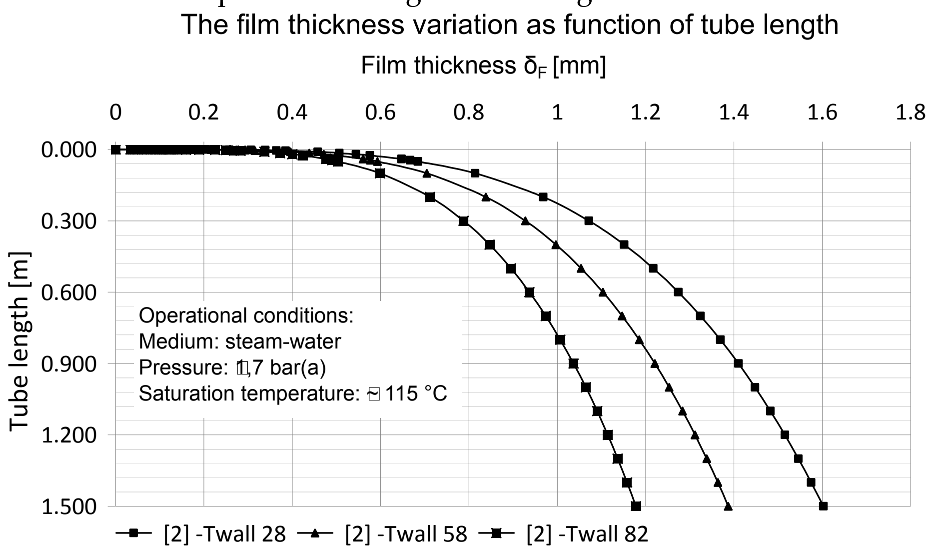

Figure 3. Expected film thickness based on the PCM material melting temperature – T_{wall}

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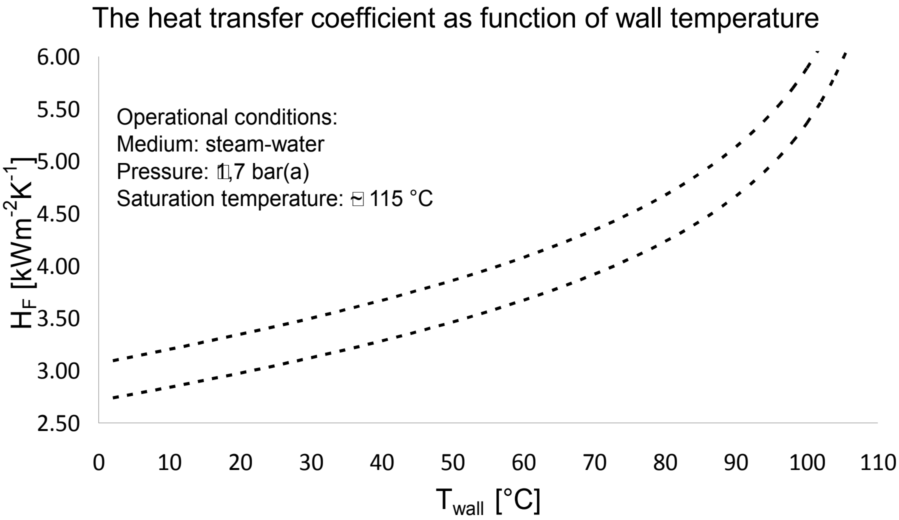

Figure 4. Expected heat transfer coefficient between two dashed lines for experiments

4. CONCLUSIONS

The experimental activities are currently under preparation. The mentioned computational results from theoretical approaches will help to design the experimental facility according to expected values of the film thickness and heat transfer coefficient. The measured data will be compared to the known equations from the condensation process and validated to the temperature measurements across to the vertical tube length and its diameter.

Considering the expected values of the film thickness to the melting temperature of PCM material is obvious that lower temperature will induce the thicker film. Following conditions from the containment it is necessary mostly focus the experiment activities based on the higher melting temperature, which is closer to the real situation during the LOCA accident.

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