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Process optimisation of a liquid sodium economiser circuit

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ABSTRACT

Economiser circuits in liquid sodium service are very common in sodium cooled fast reactor systems. Large amount of cooling in the order of 100 °C–450 °C differential temperature is common for the auxiliary liquid sodium systems such as sodium purification and impurity monitoring. A sodium to sodium heat exchanger as economiser, sodium to air heat exchanger as heat sink and electrical heater for reheating are the process equipment generally used for the liquid sodium economiser circuits. Since the specific heat transfer area and manufacturing cost for economiser heat exchanger and sodium to air heat exchanger are largely different, optimised parameters for economiser circuits with conventional heat transport medium will not hold good for liquid sodium economiser systems. An optimisation study was performed for liquid sodium economiser circuit for arriving at an optimum design by considering the technical and economical aspects with optimum energy wastage.

1. Introduction

Some of the auxiliary systems in fast breeder reactor and experimental facilities need to maintain a particular sodium temperature at a particular section of the system due to specific requirements. In sodium purification system,a portion of sodium in the order of 10 kg/sec needs to be cooled to the order of 110 °C from around 400 °C. After the sodium purification the sodium will be send back to the main system at a temperature as close to that of intake sodium. In the impurity monitoring systems like plugging indicator, hydrogen detection in sodium and carbon detection in sodium also have similar requirements. In these systems a high difference in temperature between the returning sodium and the intake sodium will result in higher energy loss and high level of thermal stresses at the mixing locations. To overcome these difficulties, an economiser circuit which achieve the same system requirements with less energy loss and returning sodium with close temperature of intake sodium is engineered.

Many testing program for fast breeder reactors require a flowing sodium atmosphere at elevated temperature in the order of 550 °C–600 °C for accelerated testing of the material and components. Electromagnetic sodium pumps are generally used in experimental facilities for circulating sodium at relatively low mass flow rates such as less than 50 kg/sec. It is not possible to circulate the sodium at this temperature by means of electromagnetic pump or mechanical pump (Sharma et al, 2011). Hence generally sodium temperature will be reduced to the range of 400 °C by means of an economiser circuit at pumping location to overcome this difficulty. An economiser circuit of this nature will have a sodium to sodium economiser heat exchanger, sodium to air finned tube heat exchanger and a sodium heater by means of immersion type electrical heaters. The schematic of normal economizer circuit is shown in Fig. 1.

Liquid metals like sodium are good conductor of heat. Hence the convective film resistance to transfer heat for liquid metal is negligible compared to the conventional heat transport mediums (IAEA, 2012). In finned tube sodium to air heat exchanger convective film resistance of air governs the overall resistance to transfer heat from sodium to air. The overall heat transfer coefficient in the sodium to sodium heat exchanger is two orders more than that of the finned tube sodium to air heat exchanger. This leads to very high specific heat transfer area requirement for sodium to air heat exchanger compared to the sodium to sodium economiser heat exchanger. Hence the design of optimized system for liquid sodium service will be quite different from that for the economiser system with conventional heat transport mediums. This paper discuss about the optimized design of the experimental system by considering various equipment and energy costs.

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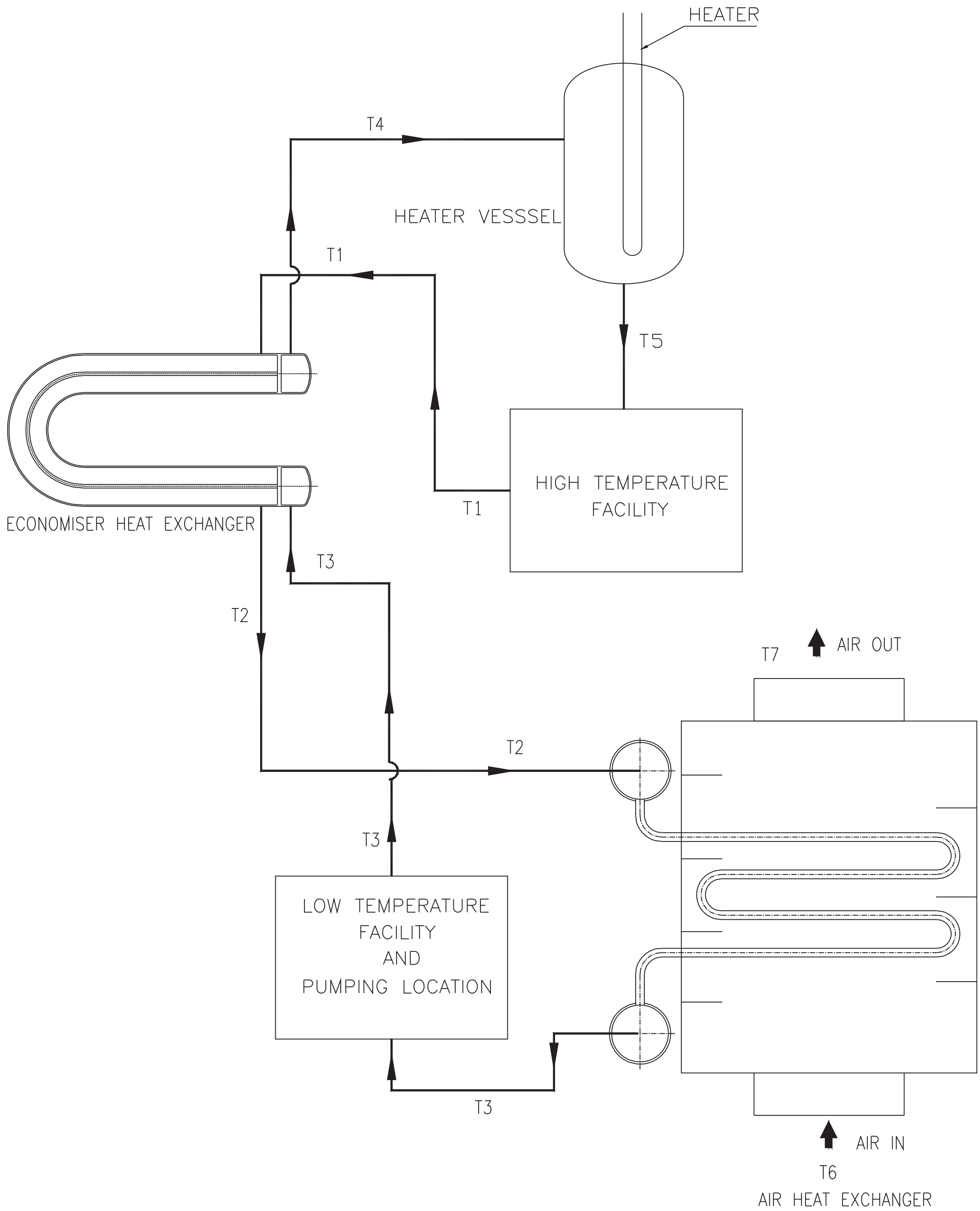

Fig. 1. Schematic of economiser circuit.

2. Cost implication of economiser circuit

EHX of the economiser circuit is a simple counter flow heat exchanger with shell and tubes arrangement and both hot side and cold side mediums are liquid sodium. The normal convective heat transfer value of the liquid sodium varies from 4000 W/m^2K to 50,000 W/m^2K (Prahlad et al., 2012). The overall heat transfer coefficient in the EHX is in the order of 5000 W/m^2K and hence the specific heat transfer area requirement is small. This makes the sodium to sodium heat exchangers compact and less expensive compared to the conventional heat exchangers. On the other hand the convective heat transfer coefficient of air is in the order of 50 W/m^2K to 75 W/m^2K with forced circulation of air around the finned tubes (Zukauskas). The film resistance offered by sodium in the tube side is negligible compare with that in air side for heat transfer. Hence the overall heat transfer coefficient of the AHX is approximately equal to the air side convective heat transfer coefficient (Vinod et al., 2013; Kannan et al., 2015; Vinod et al., 2006). Generally the mismatch between the convective film resistance for heat transfer between air side and sodium side is reduced by providing fins at air side. The poor overall heat transfer coefficient leads to comparatively large heat transfer area requirement and this make the sodium to air heat exchangers more expensive than EHX. The heat loss in the AHX is compensated by a heating the sodium by immersion type electrical heaters and increasing the sodium temperature to the original temperature to maintain the