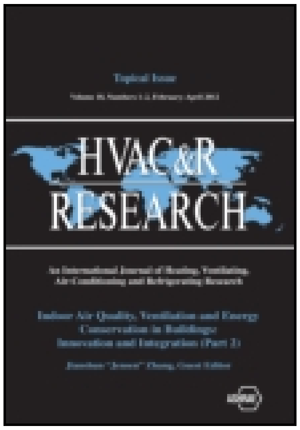

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Pipe insulation thermal conductivity under dry and wet condensing conditions with moisture ingress: A critical review

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Pipe insulation thermal conductivity under dry and wet condensing conditions with moisture ingress: A critical review

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Condensate that appears on mechanical pipe insulation systems might deteriorate the insulation thermal performance and lead to failure of the pipelines. An optimized solution that accounts for cost and system energy efficiency must consider the rate of moisture absorption at various operating conditions, and how the pipe insulation thermal conductivity varies with moisture content. This article reviews the most up-to-date work available in the public domain and observes that a controversy may exist about the similarities and differences of thermal conductivity of pipe insulation systems and flat slab configurations. Since the dissimilar behavior can be associated with the testing methodology from which the thermal conductivity values are originally derived, this article first discusses the methodologies for measuring thermal conductivity of pipe insulation systems with the intention of providing some clarification about such controversy. Steady-state and transient methods are discussed, and the measurements from these two methods are critically compared. The thermal conductivities of several pipe insulation systems are also summarized under dry operating conditions. For wet insulation, four main methods for preparing the wet samples during laboratory measurements have been identified, and it was observed that they yielded very different results. The advantages and shortcomings of each moisturizing strategy discussed at length, and the thermal conductivities of a few available pipe insulation systems in wet conditions are compared. To date, challenges still exist with the measurement of actual thermal conductivity of pipe insulation systems with moisture ingress, and future research needs in this area are discussed.

Introduction

In several industrial and commercial buildings, cooling and heating pipelines are typically insulated to maintain process conditions, to prevent excessive heat losses from the system to the surroundings, and to promote safety and health of the occupied space. When a cold surface at a temperature below the dew point is exposed to air, moisture in the air will condense on that surface. When a chilled fluid pipe is inadequately insulated, such condensate will occur, and water will drip onto other building surfaces, possibly causing growth of mold, rotting of wood, and rusting of steel. Currently, engineers design pipe insulation systems with the aim of preventing such condensation. Ideally, vapor barriers that are installed on the exterior of the pipe insulation should prevent moisture ingress, but field experience with chiller pipelines that are used to cool large buildings shows that small holes in the insulation jacket, or the presence of inadequate sealed joints allow water vapor to permeate through the insulation toward the cold surface, leading to condensation within the insulation system. This can contribute to saturated insulation as the cold pipe surface draws moisture from the air and into the insulation. This condensation releases the latent heat from the vapor to the pipe surface and, ultimately, to the pipe's fluid contents. In addition, a wet insulation is a poor insulation, whereby more energy must be spent to pay for the heat gains through the pipelines. This reduces the energy efficiency and increases the parasitic energy consumption. Wet insulation will contribute to pipe corrosion and water dripping off the pipes may degrade the performance of other building components and cause mold to grow where dripping occurs. The moisture accumulation affects the economics of the building energy performance and can lead to system failure and downtime, which causes great economic implications when considering shutdown and replacement. An optimized solution that accounts for cost and system energy efficiency must consider the rate of moisture absorption at various operating conditions, and how the pipe insulation thermal conductivity varies with moisture content. An accurate characterization of the thermal conductivity and moisture transport in pipe insulation systems would enable mechanical system designers to choose the right insulation system for the specific application and better estimate the actual heat gains during the life cycle of the insulation system. For example, if water vapor condensate on the pipelines is a vital aspect of the design, then it is helpful to know that closed-cell insulation systems are typically more resistant to the

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