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A Study on the Development of the Make-shift Heat Pump for Refugee Camp: A Case Study of Borneo State, Nigeria

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Abstract

The poor and low temperatures living conditions in the refugee camps are noted to be one of the contributing factors in the widespread of airborne related diseases. Hence, the introduction of heat pump in the camps could minimize the hazard. However, in-situ repair for copper refrigerant pipeline would be challenging due to limited resources. The objective of this paper was to study on the plausibility of utilizing aluminium tin-cans as temporary in-situ repair for copper refrigerant pipeline at the Nigerian refugee camps. In achieving this, a mathematical model of the pipeline was formulated – consisting of the thermodynamic aspects, pressure drop and maximum internal design pressure of the pipeline. The mathematical model was validated using HVAC simulation and computational fluid dynamics simulations being CoolPack and ANSYS. The mathematical model was able to prove that while the thickness of the pipe does not have a significant impact on the heat loss of the system but has a significant impact on the internal design pressure of the pipeline. The simulations were able to validate the mathematical model with the percentage errors of less than 5%. As such, the mathematical model was able to determine the optimum thickness of the pipeline being 0.12mm. From this, it is concluded that the material and the design of the pipeline is suitable for usage for in-situ repairs and maintenance at the refugee camps.

Keywords

Heat Pump, Aluminium 3004-H19, Refrigerant, HVAC

Introduction

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The United Nations High Commission for Refugees (UNHCR) created refugee camps in order to help the current political situation in Nigeria. While these camps can provide shelter and food for these IDPs at their time of need and this camp would be of focus this study. The low temperature living condition (18 to 24^{0}C in average during night-time) from the month of October to April does affect the IDPs living conditions since they are living in makeshift huts as shelter (weather et al., 2019; "Nigeria | IDMC", 2019). The low temperatures living conditions in the refugee camps in Nigeria are noted to be one of the contributing factors in the widespread of airborne related diseases (Foxman et al., 2015). In overcoming this issue, heat pumps could be used in the camps to increase the ambient temperature in the refugees' huts. Even so, in-situ repair for copper refrigerant pipeline will be challenging due to limited resources.

Fundamentally, both the heat pumps and refrigerators generally have the same components and function on the same thermodynamic principles. The main differences between the two lies in the fact the positions of the components are opposite of each other. The evaporator is placed in the space that needs to be cooled for a refrigerator while the condenser is placed in the space that is needed to be heated for the heat pump. (Afshari et al., 2018). The objective of this paper was to study on the plausibility of utilizing aluminium tin-cans as temporary in-situ repair for copper refrigerant pipeline at the Nigerian refugee camps. In achieving this, a mathematical model of the pipeline was formulated – consisting of the thermodynamic aspects, pressure drop and maximum internal design pressure of the pipeline. The use of aluminium tin-cans as temporary in-situ repair could resolve the issue on long term maintenance and cost.

Methodology

The design process of the heat pump refrigerant pipeline consists of three phases. The type of heat pump to be used is the R134a air source heat pump. The only variable in this paper that was manipulated it the thickness of the pipeline. The boundary conditions of the design was selected to be the initial temperature, pressure and velocity of the refrigerant and was set to be 70°C, 1200kPa, and 2.54 m/s respectively. The manipulated variables were the thickness of aluminium pipe. The independent and dependent variables are as listed in Table 1. The second phase was to design the refrigerant pipeline based on these variables. The pipeline was selected to use aluminium cans as its base meaning that aluminium 3004-H13 will be the base material of the pipeline. The length of the aluminium pipeline was 1m and diameter of 52 mm with thickness of 0.01mm-0.2 mm.

Table 1. List of Variables

Independent Variables	Dependent Variables
Type of Aluminium Used	The pipe's capacity to withstand pressure
Length of Pipeline	Final temperature of the refrigerant
Refrigerant Used	Heat loss of the pipeline
Velocity of Refrigerant	Pressure drop of the pipeline

Initial Temperature of Refrigerant	
Initial Pressure of Refrigerant	

The final phase was the validation of the design. The methods used was a mathematical model that focuses on the thermodynamic aspect, the pressure loss and the internal design pressure of the pipeline. The reference was the Darcy-Weisbach equation and the ASME standards used for internal design pressure for process piping (Cengel, Y., Ghajar A. and Kanoğlu M., n.d ; ASHRAE, 2005; Bereisa et al, 2005). This model was then validated using ANSYS. The validation methods were performed on the selected thicknesses (for the aluminium pipeline) and the standard copper pipe sized. The validation was based on the ASHRAE standards.

Results and Discussion

Mathematical Model

Steady state thermodynamic analysis were performed on both the aluminium pipe and standard copper pipe at the noted thickness. The results of the thermodynamic model for both pipe materials are shown in Table 2 and 3. From the analysis it was found that the heat loss difference between the minimum thickness of 0.01mm and the maximum thickness of 0.2mm is shown to only be 0.708%. While the temperature loss does increase with the heat loss, the difference between the initial and final temperature of each thickness is consistently less than 1%. Therefore, this shows that while the thickness does affects the heat loss of the system, its effects is negligible. However, when compared to the copper pipe, the heat loss is higher. While copper has a higher thermal conductivity when compared to aluminium, the differences in dimensions cause the difference in the heat loss. The increase in internal diameter causes the internal convection and natural convection to increase while the reduced thickness also reduces the thermal resistance of the pipeline itself. As for the pressure drop of the system, it was found that the pressure drop of the refrigerant in the aluminium pipe was 50.894 Pa while the copper pipe has a pressure drop 130.135 Pa. This occurs due to the copper pipe having a smaller inner diameter when compared to the aluminium pipe. While both pipelines have a very similar friction factor, the inner diameter of the copper pipe causes the pressure drop to increase.

Lastly, the internal design pressure of the refrigerant pipeline was found to determine its safety due to the high pressure of the refrigerant flow, 1.2MPa. To achieve this, equation to find the internal design pressure limit of process pipes used in ASME standards was used with a mechanical allowance of 0.5. Once the maximum internal design pressure for each thickness was found, the actual design factor of each thickness was found. The results are shown in Table 4. It was found that the design pressure of the aluminium pipeline increases with the thickness. This in turn increases the safety factor. From this, the optimum thickness of the pipeline was found to be 0.12mm as it has a safety factor is 1.036. The same process was done to the copper pipe to determine its safety, and it was found that it has a safety factor of 54.625. However, this is to be expected as this is the industry standard.

Table 2. Surface temperature of the aluminium pipes and the final temperature of the R134a refrigerant

Thickness of Pipe (mm)	Outer Diameter (m)	Heat Loss, W	Surface temperature of Pipe (°C)	Final Temperature of Refrigerant (°C)
0.01	52.02	51.998	68.818	68.765
0.05	52.10	52.076	68.817	68.763
0.10	52.20	52.173	68.814	68.761
0.15	52.3	52.271	68.812	68.759
0.20	52.4	52.386	68.810	68.756

Table 3. Surface temperature of the copper pipes and the final temperature of the R134a refrigerant

Thickness of Pipe (mm)	Outer Diameter (mm)	Heat Loss (W)	Surface Temperature of Pipe (°C)	Final Temperature of refrigerant (°C)
26.67	2.87	30.053	68.300	69.286

Table 4. Design pressure of the aluminium pipe with a safety factor of 1

Thickness (mm)	Outer Diameter of Pipe (mm)	Mechanical allowances	Design Pressure (Pa)	Safety Factor
0.01	52.02	0.5	1.03826E+05	0.086521823
0.05	52.10	0.5	5.18732E+05	0.432276657
0.10	52.20	0.5	1.03647E+06	0.863723608
0.15	52.3	0.5	1.55321E+06	1.294343241
0.20	52.40	0.5	2.06897E+06	1.724137931

CFD and FEA simulation using ANSYS

To validate the mathematical model created, CFD simulation was used. The CFD analysis was performed on three different thicknesses for aluminium pipe and standard copper pipe with the same variables as the mathematical model. It was found that the CFD simulation has shown less than 5% percentage error when compared to the mathematical model. Similar results can be found in the simulations for the copper pipeline, the percentage error for the final temperature of the pipeline and the surface temperature of the pipeline both are below 1%. For the safety factor of aluminium pipe with a thickness of 0.12mm thickness, the average was 1.205, whilst, the minimum and maximum to be 0.6027 and 8.7066 respectively. ANSYS FEA was performed to simulate the effects of the pressure of the refrigerant on the pipeline. In this simulation, only one value was needed to be evaluated, the safety factor of the pipeline. For the aluminium pipeline, the simulation was done on three thickness of 0.06mm, 0.12mm and 0.2mm. The average safety factor was compared to the safety factor found in the mathematical model and it is shown that there is a consistent 14% percentage error. This occurs due to the method used to measure the design pressure is an empirical method that used in ASME standards and ANSYS used finite element method. However, as the percentage error is consistent in all 3 cases, the mathematical model for the design pressure of the pipe is validated and concluded to be accurate.

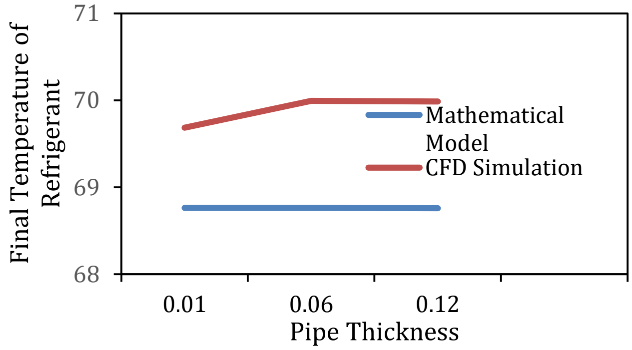

Figure 1. Final temperature of refrigerant vs pipe thickness: comparison of mathematical model and CFD simulation

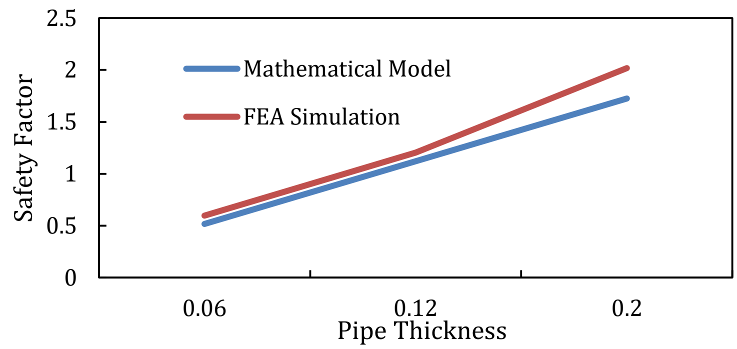

Figure 2. Safety factor against pipe thickness: comparison between mathematical model and FEA simulation

Conclusions

The objective of this paper was to study on utilizing aluminium tin-cans as temporary in-situ repair for copper refrigerant pipeline at the Nigerian refugee camps. In achieving this, a mathematical model of the pipeline was formulated. It was found that the thickness of the make-shift refrigerant pipeline does not have a huge impact on the heat loss of the system with percentage of difference between the lowest and maximum thickness of the pipeline being 0.708%. This means the thermal conductivity and the surface area of the pipe play a larger role in the heat loss of the refrigerant. The pressure drop is also not affected by the thickness of the pipeline. However, the thickness of the pipe plays a major role in determining the maximum internal design pressure of which the pipeline can handle. As such, through the mathematical model, it was found that the optimum

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thickness of the pipeline is 0.012mm as it has a safety factor of 1.036. This means that the pipeline is safe while not using too much of materials and causing overdesign of the system. This mathematical model was validated via ANSYS with percentage error of less than 5%. However, the FEA software did detect that the pipeline does have a safety factor of less than 1 at certain locations of the pipeline. While the area these locations are small, caution must still be applied when implementing this design and should only be used for temporary in-situ repair while waiting for industry standard parts to arrive.

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