JP Journal of Heat and Mass Transfer
© 2021 Pushpa Publishing House, Prayagraj, India
http://www.pphmj.com
http://dx.doi.org/10.17654/HM024010087
Volume 24, Number 1, 2021, Pages 87-96 **P-ISSN: 0973-5763**

A CONCENTRATED-PARAMETER MODEL FOR THE VALIDATION OF A TRACTOR HEATING SYSTEM DURING ARTIFICIAL WINTER CONDITIONS

Eugenia Rossi di Schio and Paolo Valdiserri

Department of Industrial Engineering DIN
Alma Mater Studiorum – University of Bologna
Viale Risorgimento 2, I-40136 Bologna
Italy
e-mail: eugenia.rossidischio@unibo.it
paolo.valdiserri@unibo.it

Abstract

In the present paper, a concentrated-parameter model is presented, in order to simulate the behavior of a climatic chamber suitably designed for testing tracked and wheeled tractors. Reference is made to standard-severe winter conditions (–18°C), i.e., the tractor dissipates thermal power in a climatic chamber that reproduces winter temperature and humidity conditions. The software package Matlab-Simulink is utilized and the system under investigation consists of 5 blocks. The dynamic modeling first covers a 10 hours period to reach the prescribed conditions for the climatic test chamber. Then, after this preparation period, the tractor's engine is supposed to work. The simulations show that higher values of the adduction coefficient are preferable since they allow obtaining quickly, and with a lower heating power, the desired comfort conditions for the machine's cabin.

Received: July 2, 2021; Accepted: August 23, 2021

Keywords and phrases: climatic chamber, numerical analysis, transient analysis, Matlab Simulink, dynamic programming.

1. Introduction

The European Regulation 167/2013 prescribes the mandatory approval test for heating, cooling and air conditioning systems, requiring experimental measures according to the European Delegated Regulation EU 2015/208 [1, 2]. In detail, the heating and cooling devices available on the tractors must be experimentally tested basing the measurements on the procedure foreseen in the ISO 14269-2:1997 standard [3]. The tests must be conducted within a climatic chamber, huge enough to host a tractor and designed to remove high heat loads during long lasting measuring times. In the literature, a few papers describe the main features of a climatic chamber, useful to reproduce external weather situations [4-6]. The papers mainly deal with experimental works.

In the present paper, we aim to numerically simulate a climatic test chamber suitable for tracked and wheeled tractors, as well as for telehandler machines, i.e., having measures $5\text{m} \times 8\text{m} \times 4\text{m}$. Reference is made to winter season use of the tractor, i.e., cooling conditions inside the climatic test chamber. During the time of measurement, the tractor engine is working, and the heat load must be removed; moreover, since the exhaust gases are immediately extracted from the climatic chamber, particular attention has to be paid to the correct estimation of the heat load to the climatic chamber, especially due to convection and radiation [7, 8].

We perform a dynamic numerical analysis by employing Matlab-Simulink. In the literature, this approach has been widely introduced, also with reference to industrial processes and buildings [9-11]. Attention will be paid to the climatic chamber, and the numerical simulation allows us to evaluate the correct sizing of the refrigerators and cooling systems needed for such chambers, by considering the transient effect of working engine as well as of working heating/cooling system on the tractor.

2. Setting of the Model

In the present paper, we aim to develop a concentrated-parameter analysis describing a climatic chamber to test the behaviour of the heating system on a tractor. A sketch of the system is reported in Figure 1. In detail, the dimensions of the climatic chamber are of $5\text{m} \times 8\text{m}$ and a height of 4m, thus displaying a volume of $160\,\text{m}^3$.

Let us assume that all the vertical and the top horizontal (roof) boundaries, i.e., a total surface of $S_S = 144\,\text{m}^2$, that bounds the climatic test chamber, are made of sandwich panels, consisting in polyurethane wrapped with a thin skin of metal, having total thickness of 180mm, thus displaying a thermal conductivity of $0.025\,\text{W}/(\text{m K})$. On the bottom part, the chamber presents a screed with characteristics and properties reported in Table 1. Since we assume for the screed a thermal conductivity of $0.8\,\text{W}/(\text{m K})$, the heat capacity of roof and vertical walls can be neglected compared with the screed's one, and roof and vertical walls can be assumed as thermally insulated.

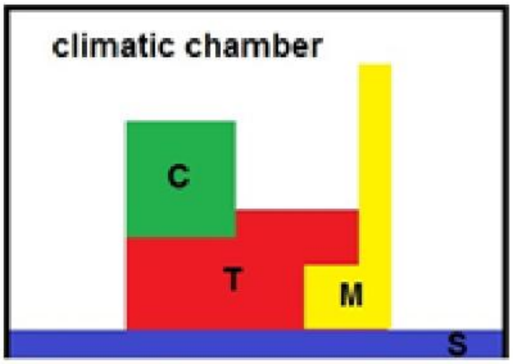

Figure 1. Sketch of the model.

The screed block must satisfy the following balance equation:

$$-S_S h[t_S - t_A] = m_S c_S \frac{dt_S}{d\tau}, \tag{1}$$

where t is the temperature, τ is the time, S is the surface, m is the mass, c is the specific heat, h is the adduction coefficient and the subscripts S and A stay, respectively, for screed and air in the climatic chamber. In equation (1), we assume t_S as the mean temperature on the screed.

In the climatic test chamber, an agricultural tractor of mass 10000kg, equipped with a 100kW power engine, is modelled as consisting in three different blocks. Block M represents the part of the machine that warms, due to the engine work, while block T represents the part of the machine that does not warm, because of its big thermal inertia. Blocks M and T are both prevalently made of steel. Block C represents the machine's cabin, totally glazed and furnished with an internal air-conditioning system (with heating power Q_C). The sizing of the three blocks is described in Table 1. A block named A is also considered, it represents the air inside the climatic chamber.

Table 1. Main characteristics of the blocks

Block	Block	Mass (volume)	Surface	Specific heat
S	screed	12000kg	$40\,\mathrm{m}^2$	$980\mathrm{J}/(\mathrm{kg\,K})$
M	tractor - warming	500kg	$10\,\mathrm{m}^2$	$480\mathrm{J}/(\mathrm{kg\,K})$
T	tractor - not warming	9500kg	$100\,\mathrm{m}^2$	$480\mathrm{J}/(\mathrm{kg\,K})$
C	cabin	$(5\,\mathrm{m}^3)$	$10\,\mathrm{m}^2$	$1006\,\mathrm{J}/(\mathrm{kg\,K})$
A	air	$(160\,\mathrm{m}^3)$		$1006\,\mathrm{J}/(\mathrm{kg\,K})$

The ISO 14269-2:1997 [3] prescribes that the tractor's engine machine in the climatic chamber is required to run at the rated engine speed, with a maximum load of no more than 20% of the maximum rated net engine power. In order to estimate hourly consumption at rated engine speed without load on the modelling, the value of 8 kg/hour of diesel fuel is utilized [4]. Different values of the adduction coefficient h between tractor and air in the chamber are evaluated.

The three blocks describing the tractor must satisfy the following balance equations:

$$Q_M - S_M h[t_M - t_A] = m_M c_M \frac{dt_M}{d\tau}, \tag{2}$$

$$-S_T h[t_T - t_A] = m_T c_T \frac{dt_T}{d\tau}, \tag{3}$$

$$Q_C - S_C C_c[t_C - t_A] = m_C c_A \frac{dt_C}{d\tau}, \tag{4}$$

where Q_M is the heat produced by the tractor's engine and Q_C is the heat provided by the tractor heating system. Moreover, in equations (2)-(4), the subscripts *M*, *T* and *C* stay for the three tractor's blocks, while *A* is for the air.

With reference to the tractor's cabin, it is full of air and the windows have thermal conductance $C_c = 5\mathrm{W}/(\mathrm{m}^2\,\mathrm{K})$. Moreover, a mass exchanged of $m_{\mathrm{ext}} = 150\,\mathrm{kg}/\mathrm{hour}$ of conditioned air is assumed between the climatic chamber and the outside. The cooling system evaporator (*Q*), having a maximum power of 400kW, extracts heat from the climatic chamber. According to the above description, the air in the climatic chamber can be described by a block fulfilling the balance equation:

$$\begin{aligned} &Q + S_M h[t_M - t_A] + S_T h[t_T - t_A] + S_C C_c[t_C - t_A] \\ &+ S_S h[t_S - t_A] + \dot{m}_{ext} c_A[t_{ext} - t_A] \\ &= m_A c_A \frac{dt_A}{d\tau}. \end{aligned} \tag{5}$$

3. Simulation Modeling Regime

The simulation regime consists of two phases. First, a preparation period: the machine enters inside the test chamber, the machine's engine is switched off and the chamber cooling system is switched on. The ISO 14269-2:1997 standard prescribes the machine cold soaked for a minimum of 10 hours prior to start the test. In this work, it is supposed that the climatic chamber has a temperature of 26°C when the tractor enters, while an initial temperature of 40°C has been assumed for the machine. This first phase has a duration of 10 hours. During the testing measurement, we need the chamber and all objects inside (namely *M*, *T* and *C*, as well as the upper surface of *S*) reaching the temperature of –18°C.

The second part is the real "test phase", i.e., a 60 minutes period during which the heat load produced by the working tractor's engine must be removed, and the heating system of the tractor has to be tested in order to fulfill the prescription of an air temperature of 20°C in the cabin.

4. Results

In Figure 2, the distribution of the temperature of the air in the climatic test chamber and of the temperature of the machine are reported, with reference to the preparation (10 hours) period.

Two different values of the adduction coefficient are reported, i.e., $h = 25\,\mathrm{W/(m^2\,K)}$ and $h = 10\,\mathrm{W/(m^2\,K)}$. As already stated, at the end the temperature of –18°C is reached. Figure 2 shows that for $h = 10\,\mathrm{W/(m^2\,K)}$, the air in the climatic chamber is cooled quickly, while the machine needs longer time. Moreover, Figure 2 shows that the initial temperature of the air in the climatic chamber is immediately higher than the initial imposed value of 26°C since the tractor, having temperature 40°C, is already present in the climatic chamber.

In Figure 3, the chilling power dynamically controlled is reported versus the measuring time. As in Figure 2, the instant $\tau = 0$ corresponds to the exact moment when the first phase starts. The figure shows that in approximately 20 minutes the power or 40kW has been reached. This power level has been maintained till the test chamber air temperature $t_A = -5^\circ\,\mathrm{C}$ has been reached. Of course, the duration of this period strongly depends on the value prescribed for the adduction coefficient *h*. Then, the power has been reduced till a minimum value which depends on the adduction coefficient: $Q = 15\,\text{kW}$ for $h = 10\,\text{W}/(\text{m}^2\,\text{K})$ and $Q = 10\,\text{kW}$ for $h = 25\,\text{W}/(\text{m}^2\,\text{K})$.

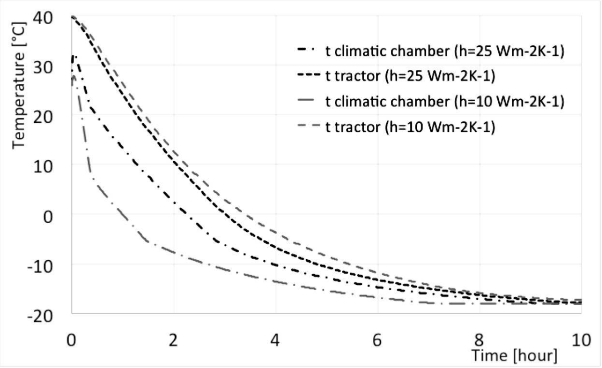

Figure 2. Air temperature and machine temperature distributions during the first 10 hours, for two different values of the adduction coefficient *h*.

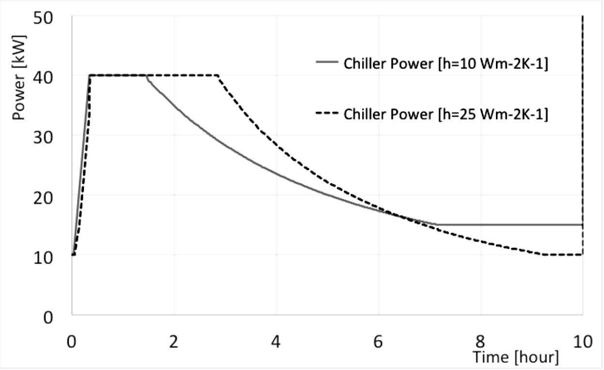

Figure 3. The chilling power in the first 10 hours, for two different values of the adduction coefficient *h*.

After the preparation phase, we check that the prescribed condition (–18°C) is reached and the 60 minutes measure test starts.

The tractor’s engine is switched on and, in order to keep the air temperature at –18°C, a cooling system having maximum power 400kW extracts heat from the chamber. The direct expansion chiller group displays in the climatic chamber is the evaporator with refrigerating fluid.

In Figure 4, the tractor's cabin temperature is reported with reference to the measuring period. Figure 4 shows the temperature in the cabin, versus time for two different values assumed by the cooling power; $\tau = 0$ corresponds to the exact moment, when the heating system onboard the tractor's cabin is switched on. The figure shows that after 15 minutes asymptotic conditions are approximately reached, for any considered value of heating power and of adduction coefficient. Moreover, the value of 20°C inside the cabin is reached with a heating power of 1.2kW if the adduction coefficient is assumed of $10\,\mathrm{W/(m^2\,K)}$ and with a heating power of 1.4kW if the adduction coefficient is assumed of $25\,\mathrm{W/(m^2\,K)}$.

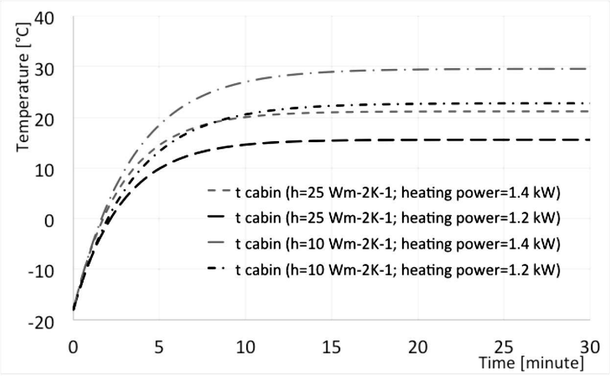

Figure 4. Temperature distributions in the machine's cabin for different values of the adduction coefficient *h* and of the heating power QC.

5. Conclusions

In the present paper, a numerical transient simulation of the behavior of a climatic chamber is presented. Reference is made to a big chamber, suitable for the testing of tractors according to the European regulation EU 167/2013 and to the ISO 14269-2:1997 regulation.

First, the balance equations are written by considering five different blocks. Then the solution is obtained by employing the commercial software package Matlab Simulink.

Reference is made to particularly quite heavy winter conditions, as prescribed by the above mentioned European regulation, i.e., a cooling chamber, separated from an environment having higher temperature. The climatic chamber is designed in order to host a machine, and to test the machine's heating system. First, a period of 10 hours is described in order to reach the required conditions for the climatic chamber. The analysis has shown that, during this period, a non-constant chilling power must be employed, dependent on the value estimated for the adduction coefficient.

After this preparation period, the machine's engine is supposed to work together with the climatization system onboard the tractor. During this test period, the analysis in the present paper has shown that with higher values of the adduction coefficient a higher heating power is needed.

References

[1] European Regulation Eu 167/2013 on the approval and market surveillance of agricultural and forestry vehicles, 2013.

[2] European Commission Delegated Act (EU) 2015/208 supplementing EU Regulation 167/2013 with regard to vehicle functional safety requirements for the approval of agricultural and forestry vehicles, 2015.

[3] ISO 14269-2:1997 Tractors and self-propelled machines for agriculture and forestry – Operator enclosure environment - Part 2: Heating, ventilation and air-conditioning test method and performance, 1997.

[4] J. Tristancho, B. Caicedo, L. Thorel and N. Obregón, Climatic chamber with centrifuge to simulate different weather conditions, Geotechnical Testing Journal 35 (2012), 159-171. https://doi.org/10.1520/GTJ103620.

[5] S. Ferrari and V. Zanotto, The thermal performance of walls under actual service conditions: evaluating the results of climatic chamber tests, Construction and Building Materials 43 (2013), 309-316.

[6] U. Pala and H. R. Oz, An investigation of thermal comfort inside a bus during heating period with a climatic chamber, Applied Ergonomics 48 (2015), 164-176.

[7] G. Bourhis and P. Leduc, Energy and exergy balances for modern diesel and gasoline engines, Oil & Gas Science and Technology - Rev. IFP 65 (2010), 39-46.

[8] T. Okamoto and N. Uchida, New concept for overcoming the trade-off between thermal efficiency, each loss and exhaust emissions in a heavy duty diesel engine, SAE Int. J. Engines 9 (2016), 859-867.

[9] M. Lorenzini, P. Valdiserri and M. Pagnoni, The role of the saver in a HPLCs heat transfer process: a transient analysis, JOP Conference Series 796 (2017), 1-9.

[10] A. W. M. van Schijndel, Integrated modeling of dynamic heat, air and moisture processes in buildings and systems using SimuLink and COMSOL, Building Simulation 2 (2009), 143-155.

[11] N. Mendes, G. H. C. Oliveira and H. X. de Araújo, Building thermal performance analysis by using Matlab/Simulink, Seventh International IBPSA Conference Rio de Janeiro, Brazil August 13-15, 2001.