

Automating the CFD analysis of Reefer Truck using PyFoam



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Abstract: CFD turned into an alluring and engineering practice utilized in the design and assessment procedure in automotive and food industries. Nowadays, open source solvers are great in demand as the small-scale industries doesn't want to invest too much into it. On the CFD OpenFOAM software front it has the capacity to handle a multi-physics problem with respect to commercial and industrial needs. OpenFoam solver is one great example which is a C++ encoded numerical tool to solve various fluid flows and heat transfer processed under lot of differential equations where the analyzer has to scratch his head to get the output. The present study involves round the designing and analyzing an OpenFoam CFD model of a Reefer truck chamber where the temperature and velocity variations were studied. The truck chamber is investigated by varying different inlet angles and changing the positions of outlet duct. And thereby automating the whole CFD process with the help of PyFoam which is an interface of Python scripting embedded with OpenFoam wherein helping the vendors or customers to directly input the coolant temperature and the inlet angle. The inlet angle at 20 degree and 45 degree was verified with the python code to conclude the CFD simulation on the reefer truck.

Keywords: CFD, Heat transfer, OpenFoam, PyFoam, Reefer truck.

I. INTRODUCTION

The dynamic increment of food consumption is because of developing total populace and riches which arouses higher food generation [1]. An ongoing methodology for dealing

with the transportation of food products is with the assistance of enhancements in transport innovations and methods of transportation.

A. Problem faced

Local fridge kept inside production lines and families is one of the fundamental electrical apparatuses and assumes a vital job in keeping hygienic and fresh food and avoiding nourishment waste. Buyers frequently believe that food is sheltered when kept in fridges with 4°C temperature specification [2]. Be that as it may, nourishment can at present ruin and can possibly cause foodborne diseases when delivered unchilled.

B. Research Objective

According to various paper referred, we have found out that researchers have automated only the solver part of analysis. In this paper, we have automated including the preprocessing, solving and post processing process. We have made it totally user-friendly using python scripting such that the customer or client doesn't have to scratch his head to apply boundary condition. The geometry automation is done in Salome to extract the python script.

C. Reefer Truck

In trucking industry definition, a "reefer" is a refrigerated trailer connected to a semi-truck which is designed so as to transport perishables and other temperature-delicate products. These trucks are required to keep up the temperature of the food inside close breaking points to guarantee its ideal safety and excellent time span of usability [3]. There are various strategies for cooling the reefer truck such as:

- Cryogen coolant - Solidified CO² ice is melted to keep substance cool
- Diesel controlled generators – These joins to the chamber being pulled

D. Need for Reefer Truck

Numerous items require chilling before ultimate delivery, with reefer trucks today carrying PCs, therapeutic supplies, plasma, blood, meats, fish, fruits and vegetables [4] Transport preservation is basic in today's civilization, to safeguard and secure nourishment, medications and medicinal supplies for individuals around the world [5].

Because of insufficient quantities and supplies of refrigerated transport vehicles in India, 37% of perishables productions items are getting squander. There are some specific food safety regulations and laws to ensure that the food is delivered within the safety standards [6].

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The nourishment conservation innovation has grown adequately to save the wide assortment of food for an extensive long time as close to the point of freshness as could be expected under the circumstances.

Extending from lifesaving meds to shipments, pharmaceutical, tobacco items, individual consideration item, fine art,

synthetic compounds and building materials. Solidified items don't require any additional additives since microorganisms don't develop when the temperature of the sustenance is beneath -9.5°C, which is adequate all alone in avoiding nourishment deterioration.

E. Computational Fluid Dynamics

CFD plays an important role when it comes to the testing and analysis of various objects or machines such as aircraft, cars, etc. All the unanswerable questions which seems to be tough long decades ago are now just available on the fingertips of analyst and engineers. For example, determining the airflow around the car, planes can be visualized and interpreted easily [7]. In this paper, we have used OpenFoam as a CFD tool to analyze the air flow simulation inside a reefer truck chamber. To meet the objectives of the multi-material science models recently referenced, a methodology should be created where fidelity CFD reproductions can be performed quickly and consequently, and where information is returned back to a driver code (e.g., IHDE) for reconciliation in the structure/investigation cycle [8].

$$\frac{D\rho}{Dt} + \rho \frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

$$\rho \frac{\partial U_j}{\partial t} + \rho U_i \frac{\partial U_j}{\partial x_i} = -\frac{\partial p}{\partial x_j} - \frac{\partial \tau_{ij}}{\partial x_i} + \rho g_j \tag{2}$$

$$\rho C_\mu \frac{\partial T}{\partial t} + \rho C_\mu u_i \frac{\partial T}{\partial x_i} = -P \frac{\partial U_i}{\partial x_i} + \lambda \frac{\partial^2 T}{\partial x_i^2} - \tau_{ij} \frac{\partial U_j}{\partial x_i} \tag{3}$$

The above equation 1, 2 and 3 depicts the continuity, momentum and energy equation respectively.

II. METHODOLOGY

The detail procedure which is followed during the execution of the project has been showed in the below Fig.1. The process involves from the literature survey to modelling to cfd solver to different boundary conditions to Automation.

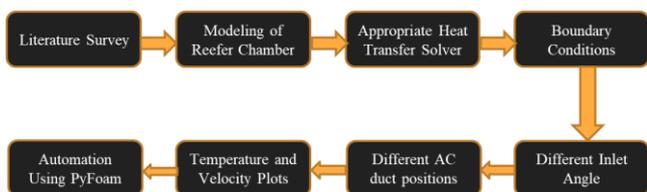


Fig.1. CAD model of reefer truck containing cargos

III. MODELLING AND ANALYSIS

A. Pre-Processing

The dimensions of reefer truck container is been studied from various paper and an average value has been fixed for

our modelling which is shown in Table I.

Table- I: Geometry Dimensions

Dimension	Value(m ³)
Inlet duct	1*0.3*0.25
Outlet duct	0.5*0.3*0.15
Reefer truck	5*2.5*2
Cargo	0.5*0.5*0.5

The truck container has been modelled in Salome Meca 2017 V0.2 shown in Fig.2. We chose this tool so that we can directly extract the geometry python script which will be useful for automation.

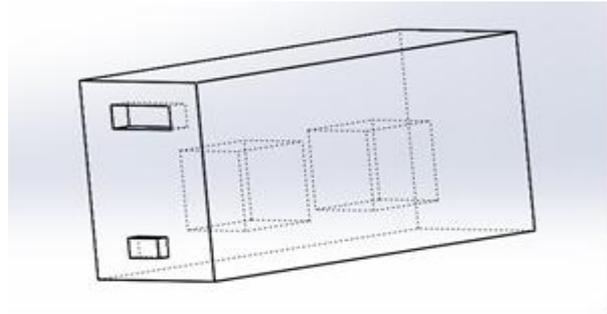


Fig.2. CAD model of reefer truck containing cargos

After modelling, various faces of the container has been assigned to input the boundary conditions such as inlet, outlet, wall and container wall.

B. Meshing

Meshing is also done in Salome. The type of mesh used is Tetrahedral Mesh as shown in Fig.3.

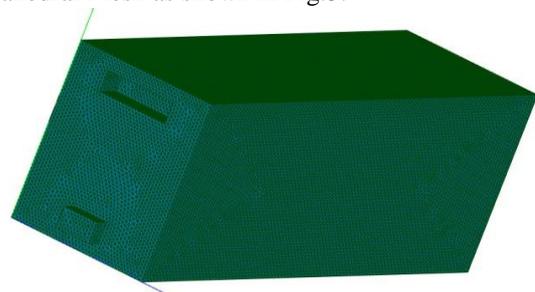


Fig.3. Tetrahedral meshing of the model

The mesh quality is defined in the following Table2

Table- II: Mesh Information

Type of mesh	Tetrahedral
Mesh size	0.05
Cells	618881
Nodes	109781
Max aspect ratio	5.64818

C. OpenFoam

This software is widely used in research purposes as it has many advantages in which one of the most important one is its free of cost since it is open source so any one can use it without even paying anything and when compared to other commercial software where we need to pay for the licenses, Despite the fact that the software is free it gives the exactly same results as the other commercial software.

There are many standard solvers in C++ coded OpenFoam Software used for various purposes. This model has been simulated under heat transfer condition. Under heat transfer condition we have used buoyantBoussinesqSimpleFoam solver as we are dealing with incompressible, steady state condition [9]. The equation 4 depicts the general form of Navier Stokes equation.

The inlet and outlet duct of the reefer truck is on the same face to keep each and every properties constant thus providing zero gradient. At the wall, the velocity is set to zero which is no-slip boundary condition. The value of alphaT, nut and other parameter are calculated based upon the Reynolds number and other parameters. Other boundary conditions are depicted in the Table.III.

$$\frac{\partial(\rho\phi)}{\partial t} + \frac{\partial}{\partial x_i} \left(\rho u_i \phi - \Gamma_\phi \frac{\partial \phi}{\partial x_i} \right) = q_\phi \quad (4)$$

Table- III: Boundary Conditions

Boundary conditions	Values
Refrigeration capacity	0.6 tonnes
Inlet velocity angle	20 ⁰
Inlet air temperature	270K
Room temperature	295K

The standard turbulence model that we have selected is RANS based realizableKE model for incompressible flow in which K determines the scale of the turbulence and epsilon determines the energy of turbulence.

D. Post Processing

The results are viewed using ParaFoam software which comes in built with OpenFoam. The contour lines, temperature and velocity plot is displayed. The graph between temperature v/s distances is plotted using a third party software called GnuPlot.

Fig.4 and Fig.5 shows the Temperature contour using ParaFoam. There are other parameters which can also be viewed such as velocity, pressure and residuals. Two cases have been considered where the inlet velocity is at two different angles i.e. 20 and 45 degrees. The outlet duct position can also be altered according to the client's requirement.

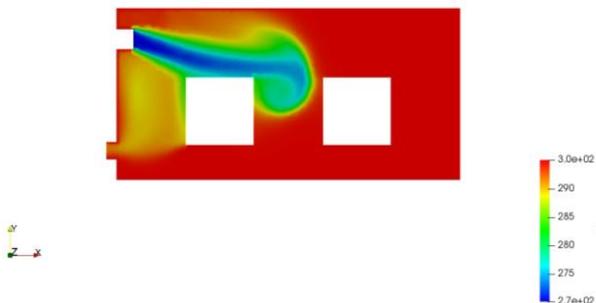


Fig.4. ParaFoam results at 50 time step

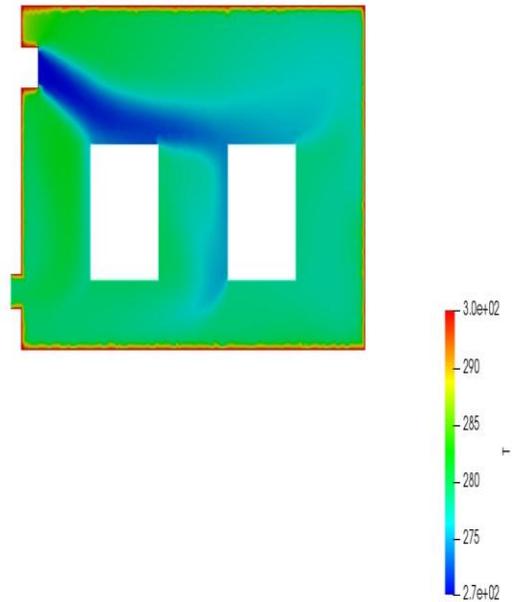


Fig.5. Parafoam results at 160 time step

IV. AUTOMATION

Nowadays, each and every system is being automated so that the customer is being felt comfortable and doesn't have to ache is head for running the process. Python makes for a brilliant universally useful scripting language reasonable for scientific calculations. Python regularly makes normal and exhausting undertakings efficient and fun [10],[11].

A. Prerequisites

The user should have installed the following database and libraries for easy functioning:

- Python 2.7
- Gnuplot
- PyFoam

B. Geometry Automation

The geometry automation is done with the aid of geometry script extracted from Salome software. The user is assigned to input the geometry dimension such as length, breadth and height of the reefer truck container. Then spacing is assigned between boxes in all the three directions(x, y, and z) to get a clear cut idea of maximum number of allocations of cargos allowed to be stacked in all the three directions as shown in Fig.6.

Step1: Assigning the dimensions of Reefer Truck

```
a = input ("\n length (A) = ")
b = input (" height (B) = ")
c = input (" width (C) = ")
data [32] = "Box_1 = geompy.MakeBoxDXDYDZ(" + str(a)
+ ", " + str(b) + ", " + str(c) + ")n"
```

This input data given by the user in the above command will be automatically updated in geometry script.

Step 2: Determining the maximum number of boxes

```
print ' x direction = ', int((p+d)/(d+0.5))
print ' y direction = ', int((q+e)/(e+0.5))
print ' z direction = ', int((r+f)/(f+0.5))
```

```

Enter the spacing between boxes in
x direction (D) = 0.5
y direction (E) = 0.2
z direction (F) = 0.25

Calculating.....

Maximum allocations of boxes allowed in
x direction = 4
y direction = 3
z direction = 2
    
```

Fig.6. Maximum allocation of boxes

p, q and r are the working area in x, y and z direction respectively wherein the cargos are stacked.

d, e and f are the spacing between the boxes in x, y and z direction respectively.

Step 3: Allocating the boxes

g = input ("Enter number of box in x direction = ")

h = input ("Enter number of box in y direction = ")

i = input ("Enter number of box in z direction = ")

Input data taken from the user are updated in the geometry script and error is shown when assigned inappropriate value.

C. Solver automation

The automation of heat transfer solver is done using PyFoam which is python embedded with OpenFoam tool. During this process, the user has to give various boundary conditions like refrigeration capacity, inlet temperature, room temperature and velocity inlet angle.

Prerequisite library functions

- From PyFoam.RunDictionary.ParsedParameterFile import ParsedParameterFile
- From PyFoam.Applications.CaseReport import CaseReport
- import os
- import math
- import subprocess

All the above library functions are required to input mathematical equations, run the process and to display various reports.

Run the mesh file

p=subprocess.Popen ('ideasUnvToFoam', 'File.unv')

The above code is to read mesh file which is in '.unv' format and convert it to Foam.

Input Boundary parameters

m = input("\n\nEnter the refrigeration capacity (Avg 0.5 to 2 tonnes): ")

p=(m/0.3)

a = input("\nInlet angle of velocity : ")

x = round(p * math.cos(a*math.pi/180.0),3)

y = round(-p * math.sin(a*math.pi/180.0),3)

The above code is to input the refrigeration capacity by the user and converting that value into inlet velocity magnitude. Similarly, other parameters are also assigned.

To display the report

CaseReport ("--long-bc.")

This code will allow the user to display and view all the boundary conditions and if any correction is there then it

request the user to alter the value.

Running the Simulation

p=subprocess.Popen ('buoyantBoussinesqSimpleFoam')
Subprocess allows the user to run the simulation wherein the name of the solver is already been slot in. Since, it is a steady state condition, the simulation will get converged at a particular time step. The time required for simulation depends upon mesh size, geometry, deltaT and velocity.

Plotting the graph

p=subprocess.Popen(['postProcess-func singleGraph'])

The graph is plotted with the aid of a third-party software called Gnuplot where readings are stored at each time step as shown in Fig.7 and Fig.8. Before viewing the results, the user has to define coordinate points at which the graph has to be plotted as in (x₁, y₁, z₁) and (x₂, y₂, z₂).

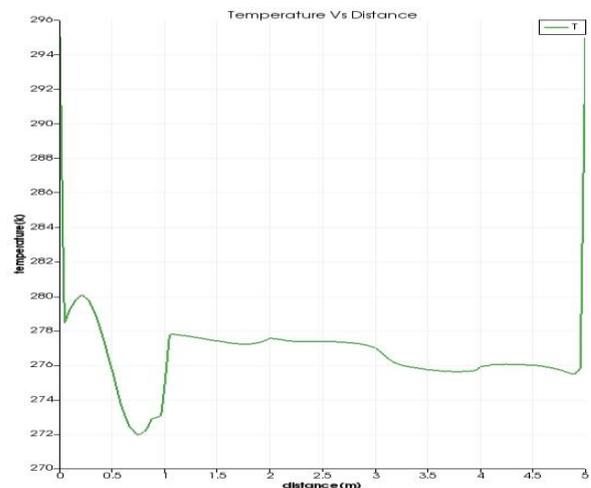


Fig.7. Gnuplot of Temperature v/s Distance for 45⁰ angle

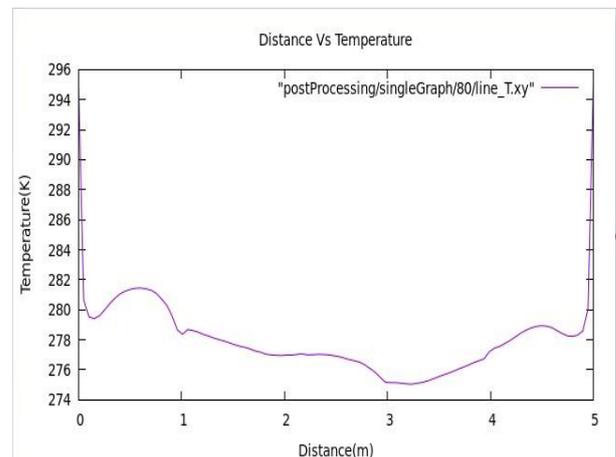


Fig.8. Gnuplot of Temperature v/s Distance for 20⁰ Angle

Define abbreviations and acronyms the first time they are used in the text, even after they have.

V. CONCLUSION

In a focused profitable center, the organizations that get their items to advertise quickest, limit their stock expenses and get the most stretch – actually and collectively – out of their ground provision or conveyance fleets are the ones that succeed. Numerous organizations are automating their coordinations forms by setting up supply chains that associate them with their clients and providers. In this paper, automation of CFD analysis of air flow inside a reefer truck is been programmed with the aid of OpenFoam and PyFoam Tool. The user have to just put the input parameters that are required for cooling of cargo. The automation includes cargo pallet's arrangement in all the three direction where the user just have to put spacing between the boxes and it will automatically calculate the maximum allocation of boxes. Apart from that, the whole CFD process including the plotting of graph is automated through which the client or the user has the liberty to alter any parameters to maximize his profit. There are some constraints in the process where the user has to manually export the geometry file to solver. The project and this research study can be extended by considering other factors into account such as heat flux, friction wear, gravity effect, transient condition and other external factors which should be considered for realistic condition.

REFERENCES

1. M Setiyo, B Waluyo, B C Purnomo, D W Karmiadji, and IC Setiawan, "Potential of ½ cycle refrigeration system for food transport application" I. O. P. C. Series and M. Science pp. 0–6, 2018.
2. K. Ye, J. Wang, Y. Han, C. Wang, C. Qi, and X. Ge, "Investigation on microbial contamination in the cold storage room of domestic refrigerators," Food Control, vol. 99, no. December 2018, pp. 64–67, 2019.
3. S. Getahun, A. Ambaw, M. Delele, C. J. Meyer, and U. L. Opara, "Analysis of airflow and heat transfer inside fruit packed refrigerated shipping container: Part I Model development and validation," J. Food Eng., 2017.
4. S. Aghazadeh, "Viewpoint Improving logistics operations across the food industry supply chain," International Journal of Contemporary Hospitality Management, pp. 263–268, 2004.
5. E. U. T. Van Velzen and L. J. S. Lukasse, "Improving Hygiene in Food Transportation." Elsevier Ltd, 2016.
6. Rahul Jain and R.C. Gupta, "Optimum Insulation Thickness for Reefer Truck," International Journal of Thermal Technologies, vol. 2, no. 1, pp. 141–147, 2012.
7. F. Roelofs and A. Shams, "CFD—Introduction," 2019.
8. P. Mirade and P. Animaux, "Computational fluid dynamics (CFD) modelling applied to the ripening of fermented food products : Basics and advances," vol. 19, pp. 472–481, 2008.
9. H. Jasak and A. Jemcov, "OpenFOAM : A C ++ Library for Complex Physics Simulations ", International Workshop on Coupled Methods in Numerical Dynamics, vol. m, pp. 1–20, 2007.
10. K. R. Srinath, "Python – The Fastest Growing Programming Language", International Research Journal of Engineering and Technology (IRJET) pp. 354–357, 2017.
11. K. L. Cristiano and D. A. Triana, "Python script used as simulator for the teaching of electric field in electromagnetism course," 2019.

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