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Research Article

Optimum Insulation Thickness for Reefer Truck

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Abstract

The main objective of this paper is to analyze the best insulation material and optimum insulation thickness and airflow pattern using results obtained from computational fluid dynamics module FLUENT. This deals with the computational fluid dynamics analysis of flow in Reefer truck. This involves with the three dimensional analysis of flow through a Reefer truck having inlet and outlet. The software used for this purpose is CATIA v5 and ANSYS 13.0. The three dimensional model of the Reefer truck are made by CATIA v5 and analysis are to be carried out by module FLUENT. The models are first generated using the data and then meshed after that various velocity and pressure contours are to be drawn and graphed in this paper to analyze the flow. Various graphs indicating the variation of velocity, pressure and temperature of the Reefer Truck are given. In experimental work, take pull up and pull down readings of reefer truck. This paper strongly focused on optimum insulation thickness and lowest cost insulation material which give best results and to reduce weight of reefer truck.

***Keywords**: Computational fluid dynamics module fluent, reefer truck, RSM model, k-ξ model*

1. Introduction

a).Need for Reefer Truck

37% of total productions of perishables products were waste due to lack in numbers of Refrigerated transport vehicles in India. The food preservation technology has developed sufficiently to preserve the wide variety of foods for a considerable long time as near the point of freshness as possible. Principle of food handling and distribution is that the product will be maintained at suitable conditions from the time it is prepared to the time it is eaten. Products, involved are candy, beverages, meat, poultry, fish, bakery and dairy products fruits and vegetables. Refrigeration such as in chilling, freezing. Ranging from lifesaving medicines to shipments, Pharmaceutical, tobacco products, personal care product, fine artwork, chemicals and engineering materials. Frozen products do not require any added preservatives because microorganisms do not grow when the temperature of the food is below -9.5°C, which is sufficient on its own in preventing food spoilage. Pathogens are more likely to be able to survive cold temperatures rather than hot temperatures.

b).Description of Reefer Truck

A refrigerator truck is a designed to carry perishable freight at specific temperatures. Refrigerator cars differ from simple insulated boxcars and ventilated boxcars (commonly used for transporting fruit), neither of which are fitted with cooling apparatus. Reefers can be ice-cooled, come equipped with any one of a variety of mechanical refrigeration systems, or utilize carbon dioxide (either as dry ice, or in liquid form) as a cooling agent. Milk cars (and other types of "express" reefers) may or may not include a cooling system, but are equipped with high-speed trucks and other modifications that allow them to travel with passenger trains.

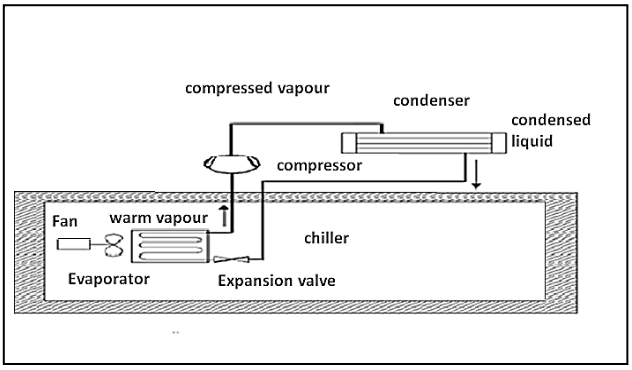

Figure 1.1 Schematic diagram of reefer truck

2. Simulation setup

a).CATIA V5- CATIA version 5 is a process-centric CAD/CAM/CAE system, CATIA v5 builds on powerful smart modeling concepts to enable the capture and reuse

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Table 1 boundary conditions of reefer truck

	Formula	Values
Outer Volume	4.03m * 0.76m * 0.909m	2.784 m^3
Inner Volume	3.93m * 0.66 * 0.808m	2.096 m^3
Outer Surface Area	2(4.03m * 0.909m + 4.03m *0.76m + 0.76 * 0.909m)	14.834 m^2
Inner Surface Area	2(3.93m * 0.808m + 3.93m *0.66m + 0.66m * 0.808m)	12.61 m^2
Outlet	0.18m * 1.22m	0.219 m^2
Inlet	1.1 m * 0.12m	0.132 m^2

of process specifications and intelligence. The result is an easily scalable. CATIA v5 has an innovative user interface. CATIA v5 applications are based on a hybrid modeling technology. Here model was made on CATIA v5.

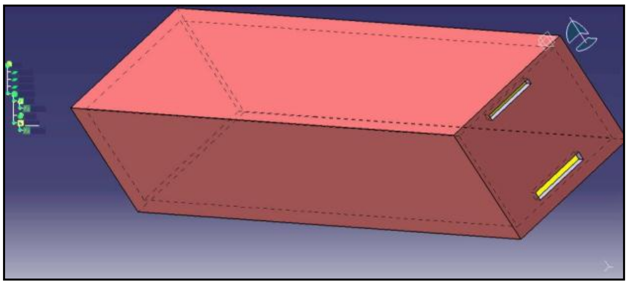


Figure 1.2 CATIA model

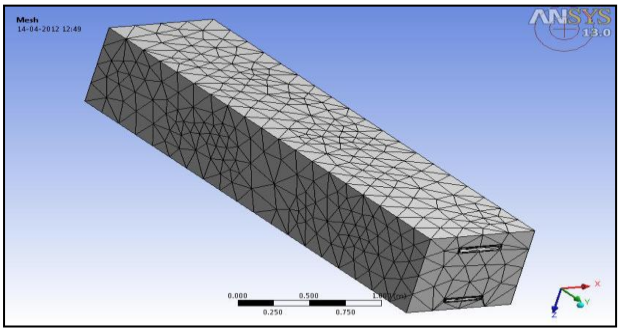


Fig. 1.3 Meshing

b). Meshing

Is an integral part of the Computer-Aided Engineering (CAE) analysis process. The mesh influences the accuracy, convergence and speed of the solution. Furthermore, the time it takes to create a mesh model is often a significant portion of the time it takes to get results from a CAE solution. Therefore, the better and more automated the meshing tools, the better the solution. In this first define inlet and outlet and then click on generate mesh.

c). CFD

With the rapid advances in computational power of recent years, the use of CFD technique in this application has become popular. CFD models are more and more often used to calculate transfer coefficient values. Experimental knowledge is reviewed and way it can be used by scientist and engineer to determine their own transfer coefficient values is illustrated. CFD has been used to investigate the optimization of air distribution in refrigerated vehicle in order to decrease temperature variation with in loaded space. A reduced scale model and CFD predictions are used to investigate experimentally and numerically the airflow pattern with in refrigerated truck. The numerical predictions obtained with computational fluid dynamics package using RSM turbulence model showed a satisfactorily agreement with experimental data in high velocity zone. The turbulence model chosen for the simulation is a standard k-ξ model.

3. Methodology

Reefer truck model was prepared in CATIA v5 by taking boundary conditions [4] than this model was imported in ANSYS13.0 FLUENT module after that meshing was done. After that in SETUP specify boundary conditions. First analysis by changing insulation thickness (20mm ,40mm ,50mm ,60mm ,70mm ,80mm ,100mm)while fixing insulation material as PUFF and then changing insulation material (polyureathane, polystyrene,bitumen, polyisocyanurate, plasterboard) while fixing insulation thickness as 60mm. then comparative analysis of contours of velocity distribution, density distribution, temperature distribution, pressure distribution, path lines , turbulent kinetic energy . Pull up and pull down readings recorded by digital thermometer and make comparative study to find optimum insulation thickness and best insulation material.

Table 2 Design values taken for analysis

Parameters	Values
Design temperature	-10 ° C
Inlet temperature	-20 ° C
Atmospheric temperature	45° C
Turbulent kinetic energy	0.09 m^2 / s^2
Turbulent dissipation rate	16 m^2 / s^3
Velocity inlet	2.5 m / s
Airflow volume	680 m^3 / hr

Table 3 Thermodynamic Property of Insulation materials

Properties	Polyurethane	Polystyrene	Bitumen	Polyisocyanurate	Plaster board
Thermal conductivity (w/m K)	0.29	0.036	0.17	0.027	0.21
Density (kg/m^3)	64	60	1200	35.9	900
Specific heat (kJ /kg K)	1.5	1.3	1	0.03	1
Overall heat transfer coeff (w/K.m^2)	1.41	0.88	5.56	0.1389	3.584

Table 4 cooling capacity calculations

Terminology	Formulas	Values
Mass Flow Rate	Volume flow rate / specific volume	2 kg / min
Cooling system	m(h1-h4)/210	1.182 ton of refrigeration
COP	(h1-h4) / (h2-h1)	2.32

Table 5 heat gain calculations for various insulation materials

Heat Gain	Q = U * A * (t_a – t_s)	Q (Watts)
Polyurethane	Q =1.41 * (2*4.03*0.909*0.76) * (45-(-10))	431.8
Polystyrene	Q =0.88 * (2*4.03*0.909*0.76) * (45-(-10))	269.5
Bitumen	Q =5.56 * (2*4.03*0.909*0.76) * (45-(-10))	1702.75
Polyisocyanurate	Q =0.139*(2*4.03*0.909*0.76) * (45-(-10))	42.569
Plaster board	Q =3.58 * (2*4.03*0.909*0.76) * (45-(-10))	1096.375

Table 6 mass of chamber calculations for various insulation materials

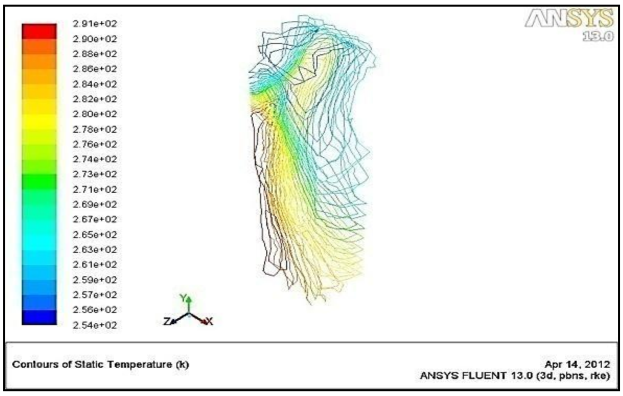
Mass of chamber	Density * (outer volume – inner volume)	M (kg)
Polyurethane	M = 64 * (2.784-2.096)	44.032
Polystyrene	M = 60 * (2.784-2.096)	41.28
Bitumen	M = 1200 * (2.784-2.096)	825.6
Polyisocyanurate	M = 35.9 * (2.784-2.096)	24.7
Plaster board	M = 900 * (2.784-2.096)	619.2

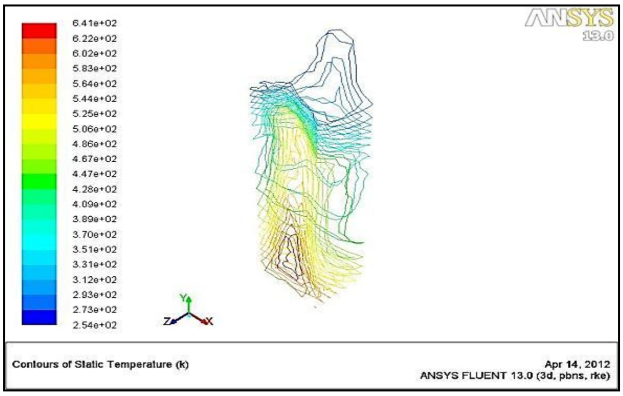
Table 7 Sensible heat, latent heat, and sensible heat factor calculations

Terminology	Formulas	Calculation	Values
Mass of air supplied	V_1/V_{s1}	11.33 / 0.73	15.52 Kg / min
Sensible Heat	$m_a(h_3-h_2)$	15.52 * (-9.5-(-18))	131.92 KJ / min
Latent Heat	$m_a(h_1-h_3)$	15.52 * (-7-(-9.5))	38.8 KJ / min
Sensible Heat Factor	SH/(SH+LH)	131.92 / 170.72	0.77

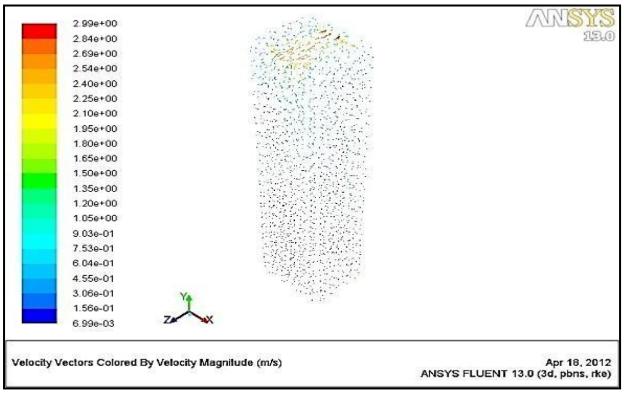
5. Results

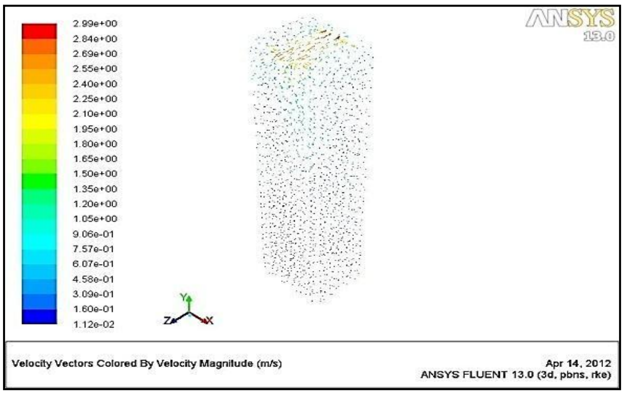
a) Contours of static temperature



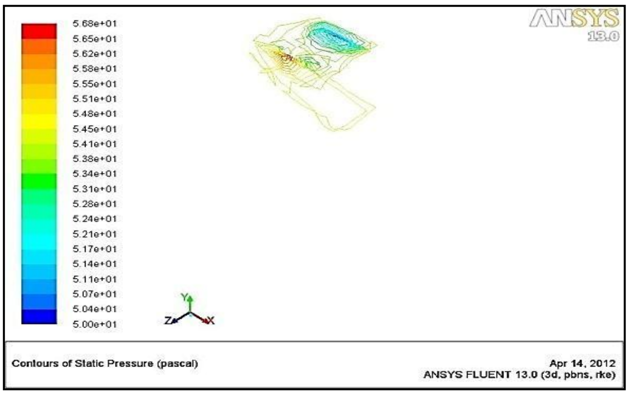


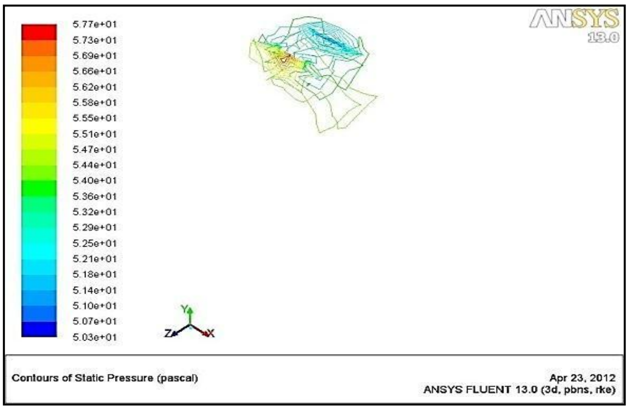
b) Contours of velocity



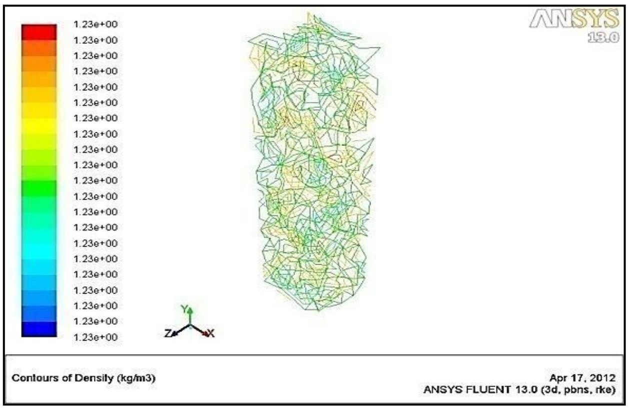


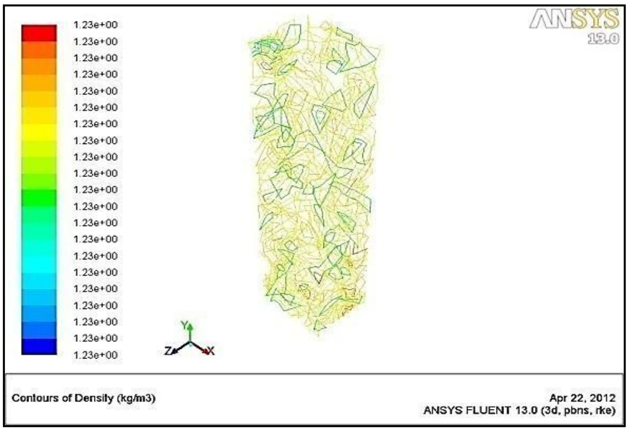
c) Contours static pressures



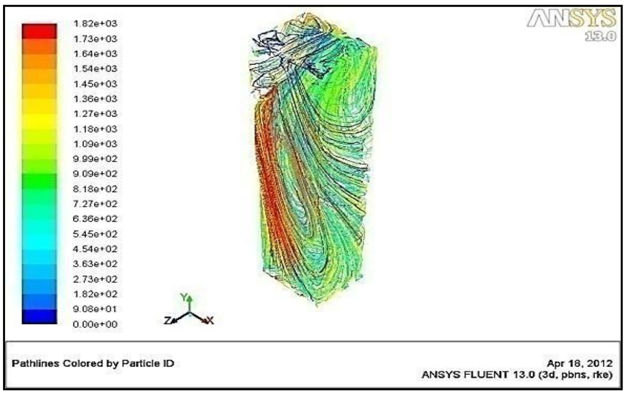


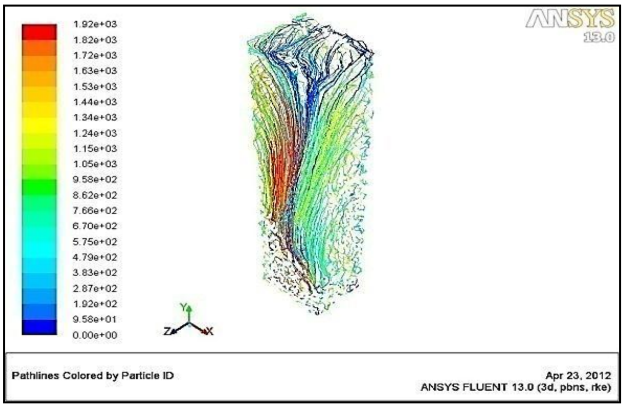
d) Contours of density



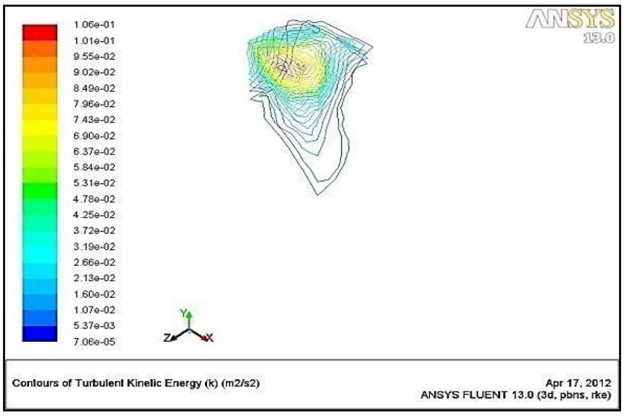


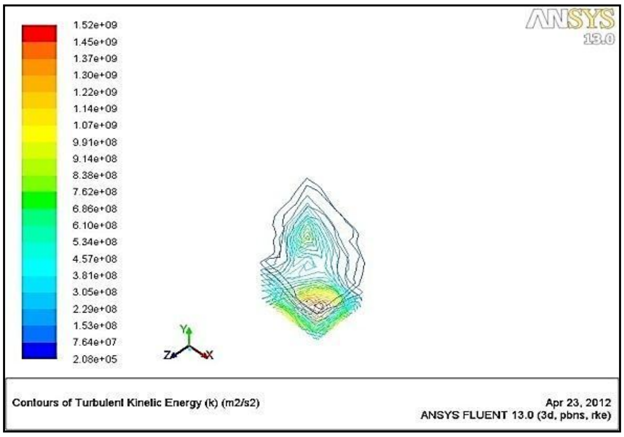
e) Contours of path lines



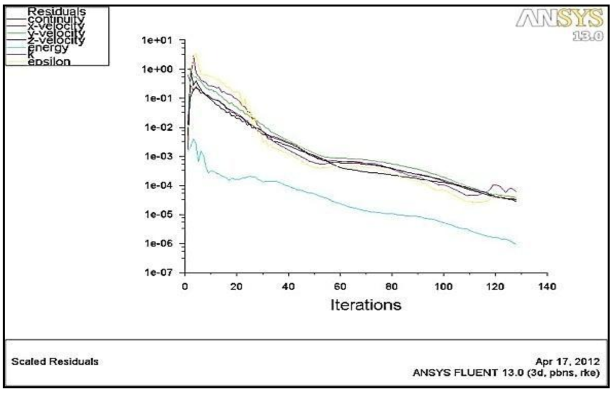


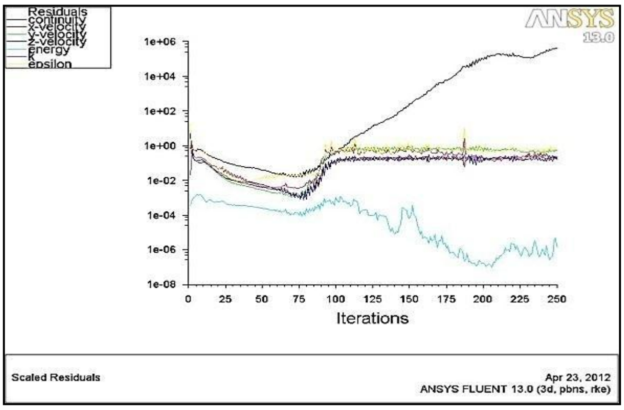
f) Contours of turbulent kinetic energy



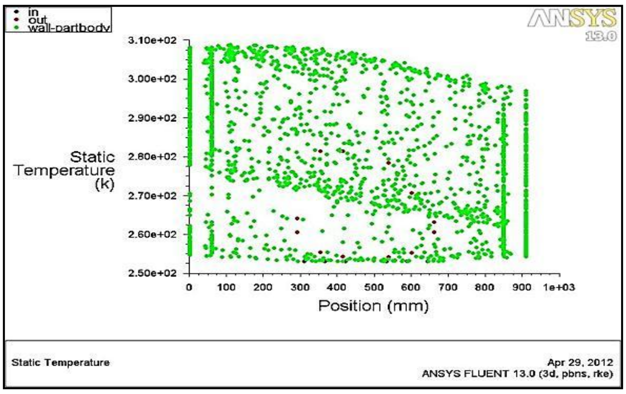


g) Velocity graph





h)Temperature graph



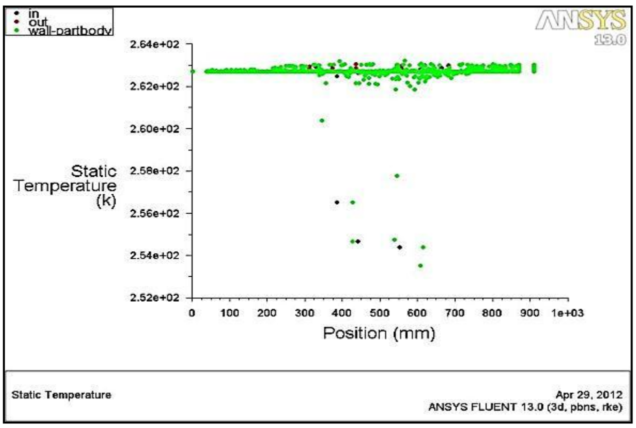


Table 8: Results in tabulated form by changing insulation thickness and fixing insulation material as PUFF

Insulation	20 mm	40 mm	50 mm	60mm	70 mm	80 mm	100 mm
Pressure (Ps)	$4.69*10^{14}$	$8.308*10^{12}$	58.882	54.233	58.09	57.879	59.166
Density kg/m^3	1.225	1.225	1.225	1.225	1.225	1.225	1.225
Velocity(m/s)	$1.753*10^{8}$	$7.955*10^{6}$	3.012	2.993	2.964	3.116	3.0165
Temperature K	1039.87	263.2143	287.89	264.457	622.23	316.15	364.55
Turbulent kinetic energy (m^2/s^2)	$4.644*10^{11}$	$2.864*10^{9}$	0.149	0.006	0.139	0.4976	0.4357
Viscosity kg/ms	$1.789*10^{-5}$	$1.789*10^{-5}$	$1.789*10^{-5}$	$1.789*10^{-5}$	$1.789*10^{-5}$	$1.789*10^{-5}$	$1.789*10^{-5}$

Table 9: Results in tabulated form by changing insulation material and fixing insulation thickness as 60mm

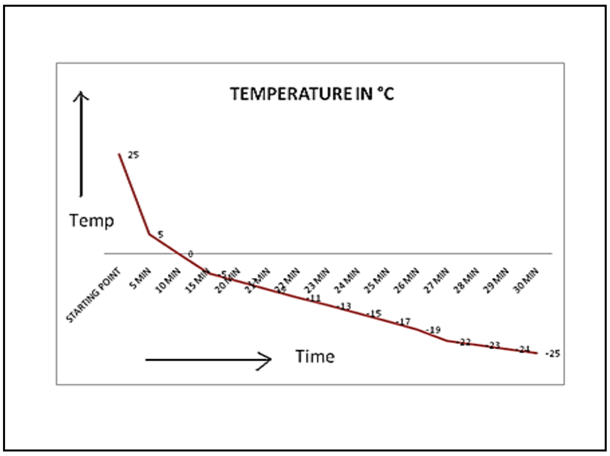
Insulation	Puff	Plaster board	Bitumen	Polystyrene	Polyisonurate
Pressure (Ps)	54.233	58.478	58.54	58.539	58.5386
Density kg/m^3	1.225	1.225	1.225	1.225	1.225
Velocity(m/s)	2.993	2.996	2.9926	2.99253	2.992
Temperature K	264.457	310.517	301.484	277.6	259.73
Turbulent kinetic energy(m^2/s^2)	0.006	0.272	0.318	0.3179	0.3183
Viscosity kg/ms	$1.789*10^{5}$	$1.789*10^{5}$	$1.789*10^{5}$	$1.789*10^{5}$	$1.789*10^{5}$

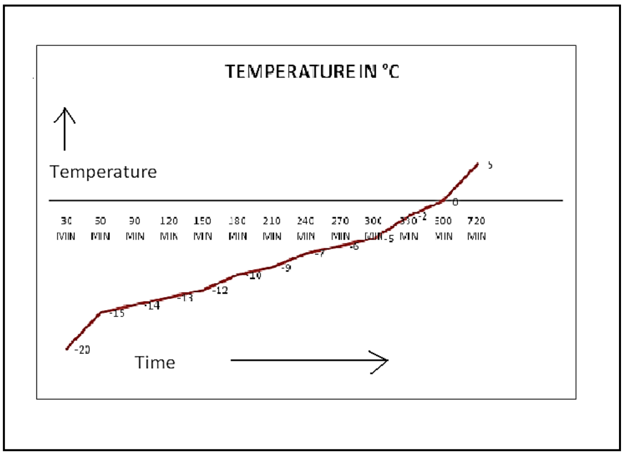
Table 10: Comparative study of velocity and Temperature in the form of experimental verses CFD results

Parameters	Experimental	CFD	% Difference
Inlet velocity (m/s)	2.5	3	20
Velocity at mid point (m/s)	1.4	2.1	50
Maximum Temperature (K)	285	282	1.1
Minimum Temperature (K)	253	252	0. 4

Experimental Readings

PULL UP and PULL DOWN Temperatures





From anemometer readings as velocity varies from 2.5m/s to 0.4m/s and from digital thermometer temperature varies from 253 K to 285 K

4. Conclusion

From graph of pull up and pull down readings it is calculated that time takes to cool from 25°C to -25°C was 30 minutes when the air conditioner was on and time takes from -20°C to 5°C was 720 minutes when the air conditioner was switch off. From comparative study best insulation material was polyisocyanurate because of lowest heat gain (42.569 watts), mass of chamber (24.7 kg) also its thermal properties such as thermal conductivity (0.027w/m K), density (35.9 kg/m^3), specific heat (0.03 KJ/kg° C), and Heat transfer coefficient(0.1389 w/K.m^2) were also lowest when compared to other insulating material**.** And from comparative study of velocity and temperature graphs of 20mm,40mm,50mm,60mm,70mm,80mm and 100mm optimum insulation thickness was 60 mm because velocity (3 m/s to 0.1 m/s) and temperature(282 K to 253 K) . So there is need to install duct so that uniform velocity distribution can be achieved.

5. Discussion of results

1. The CFD modeling and simulation of reefer truck represents relatively speedy and economical alternatives to experimental studies.
2. The CFD analysis can incorporate the actual details of the geometry, material properties and boundary conditions to produce complete and detailed information about the distribution of temperatures, velocities.
3. In order to validate the CFD models, experimental testing is necessary.
4. On the other hand, the CFD Predictions has been used to plan and design the experiments, to significantly reduce the amount of experimentation and to supplement and enrich the experimental results.
5. CFD predictions show that the directions of airflow at inlet play an important role in formation of flow patterns.
6. As the results of different airflow patterns, the temperature distribution, heat flux distribution and total heat transfer may vary significantly.
7. The boundary and test conditions for these two experiments were replicated in CFD model simulations.
8. The CFD model was refined progressively based on comparison with analytical results. The comparison between the final results of the model calculations and test data demonstrates that CFD model is capable of simulating the reefer truck airflow pattern, temperature, velocity, heat flux and total heat transfer with acceptable accuracy.

6. Scope for future work

To be able to predict accurate heat transfer and thus temperatures, in food products in a refrigerated transport container a model needs to include:

- Conduction through the wall
- Heat transfer between the container wall and the refrigerated air.
- Heat removed from the air by refrigeration system.
- Heat transfer between the container fittings and the refrigerated air.
- Heat transfer between the food and refrigerated air.
- Heat transfer between the container wall and the outside air.

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