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Validation of Earth Air Tunnel Heat Exchanger CFD Model To Experimental Setup

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Abstract: The CFD based earth air tunnel heat exchanger modelling is validated by taking the observations of an actual earth air tunnel heat exchanger fabricated at Ajmer (Western India). The experimental observations was taken on March 12, 2009 and repeated on April 08, 2009 at Ajmer. The experiment flow of air is made through the material of PVC and steel pipes separately. The two horizontal cylindrical pipes of 0.15 m inner diameter with the buried length of 23.42 m made up of PVC and mild steel pipes and buried at a depth of 2.7 m in a flat land with dry soil. The two pipes viz. PVC and steel are connected to common intake and outlet manifold for air passage. The observations were taken for flow velocities 5 m/s.
A study state and implicit model based on computational fluid dynamics was developed to predict the thermal performance and cooling capacity of earth air tunnel heat exchanger systems. The model was developed inside the FLUENT simulation program. The model developed is validated to experimental set-up in Ajmer (Western India). A thermal model was developed to analyze thermal energy accumulated in soil/ ground for the purpose of room cooling of buildings in the desert (hot and dry) climate of Bikaner.
Keywords: *Thermal conductivity, CFD, Temperature, Velocity, Earth Air Tunnel Heat Exchanger.*

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I. INTRODUCTION

The present condition of the world is facing problems in energy scarcity as we are depleting fossil fuels. So we are need of finding out alternative energy sources which can satisfy the energy needs of the future generation. Unconventional energy sources are better option which is non exhaustible and can be found more on the earth surfaces [1]. Air-conditioning are commonly used in households and industrial applications for cooling. The commonly used refrigerants are CFCs which depletes the ozone layer of the atmosphere and hazardous gas which is dangerous to human being when it's inhaled. In order to eliminate this problem scientists are developing ecofriendly refrigerants. Also to reduce energy consumption and use of high grade energy the alternative technologies are developed by the scientists [2, 3]. In these on of the best alternative is EATHE. In the ground depth of 1.5 to 2.5 m the temperature will remain constant and it will be equal to annual average temperature of that locality. This constant temperature of the ground will remain higher in winter and lower in summer. EATHE are made up of metallic, plastic or concrete materials which is buried inside the ground of particular length which can be used for heating in winter and cooling in summer. This device utilizes the heat capacity effectively as there are less losses involved in this device. Soil at the depth which the pipes are buried will be a source in winter and sink in the summer condition. EAHE system can be used sufficiently if the heating and cooling system are enough to meet the loads. In case if the heating/cooling is not sufficient from the EATHE system, an additional cooling system can be provided whose energy requirements will be reduced. Many researchers have find out that EATHE can reduce the energy consumption enormously and it can be used for building heating and cooling conditions [4–6]. The important factors which affect the performance of EATHE system are surface condition, temperature and moisture [7]. The classification of the site for EATHE is based on the geological properties. It also depends on the physical, thermal properties, depth of water, depth of bed rock etc. [8–15].

II. METHODOLOGY

The computational fluid dynamic (CFD) are a powerful method to study heat and mass transfer from many years. CFD codes are structured around numerical algorithms that can tackle fluid flow problems. CFD provides the numerical solutions of partial differential equations witch governing airflow and heat transfer in a

discretised form. The complicated fluid flow and the heat transfer processes involved in any heat exchanger can be examined by
CFD software, FLUENT 14.5. The CFD codes in FLUENT contain three main elements as shown in fig.1.

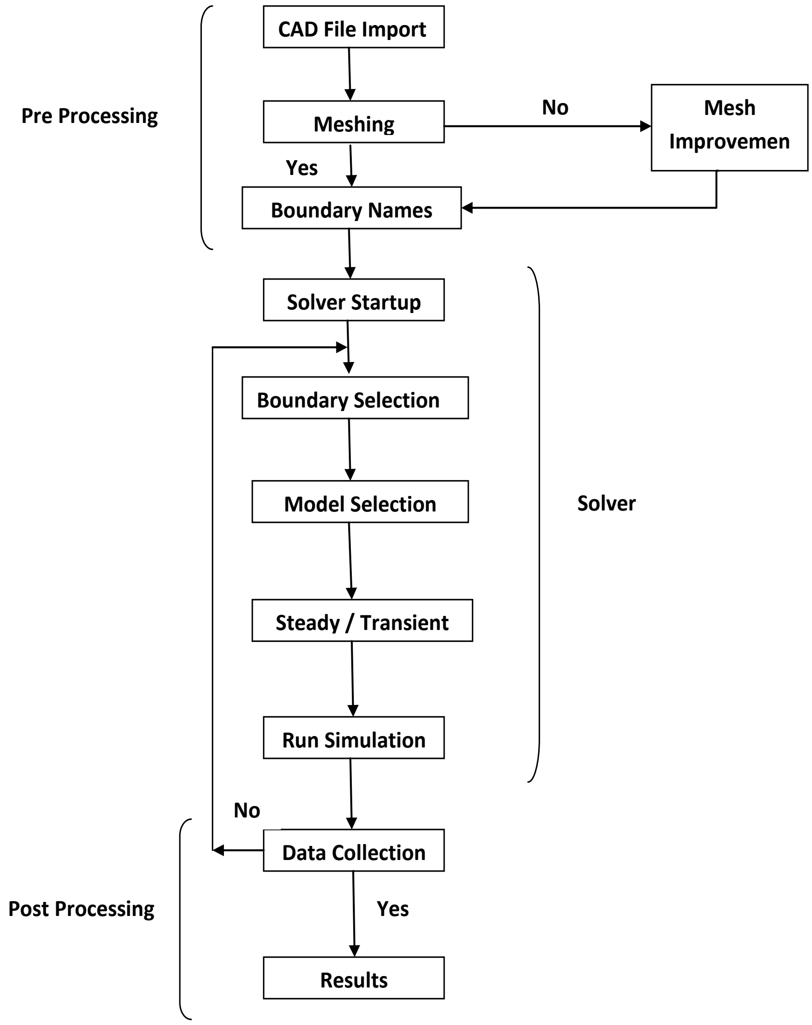

Fig.1 Flow Chart of CFD Methodology

(i) Pre-processor
(ii) Solver
(iii) Post-processor.

i. Pre-processor are consists of input of a flow problem to a CFD program by means of definition of geometry of the region of interest. The CFD domain generating grid to subdivision of fluid domain. The domain is dividing into a number of sub domains. The sub-domains are a grid (or mesh) of cells (or control volumes or elements), with or touch the domain boundary.
ii. Solver uses finite control volume method for solving the governing equations of the fluid flow and heat transfer.
iii. Post-processor shows results of the simulations using vector plots, contour plots, graphs, animations, etc.

Model Specifications

The present CFD EATHE model is prepared by using CATIA P3 V5R14. The CATIA is very important tool for preparing geometry. Since EATHE model is of cylindrical shape we are considering the three parts via outer, middle and, inner which are the material of soil, steel and air (fluid).

Geometry

After create EATHE model in CATIA P3 V5R14 the ANSYS 14.5 work bench open and creating the fluid flow (fluent) in ANSYS 14.5 work bench. The EATHE model is import in ANSYS 14.5 work bench fluid flow (fluent) geometry which is shown in fig.2.

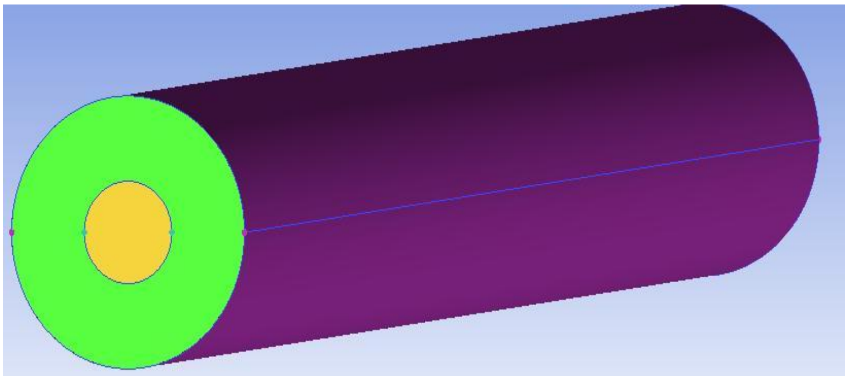

Fig.2 Geometry of EATHE model

Meshing

The next step in pre-processing stage is generation of mesh to be used in the ANSYS FLUENT. ANSYS ICEM is used for generating the mesh of the geometry. The tetrahedral meshing is used for mesh the EATHE model which is shown in fig. and fig. shown the enlarged view of meshing. Since our geometry is quarter third part, so the symmetry is created for the meshing operation which is shown in fig.3. Since air enters from the one end of the pipe this is the 'inlet' and leave from 'outlet' created in the model. In the present analysis, CFD simulations performed using an unstructured grid. The mesh is used proximity and curvature based. One of the geometry meshing algorithms picks different mesh method by default. The sizing parameters are selected based on size of model. The 'relevance center' and 'smoothing' specification of the both mesh are set to fine. The minimum element size and maximum element size both are set to 5.34 mm and 683.85 mm respectively.

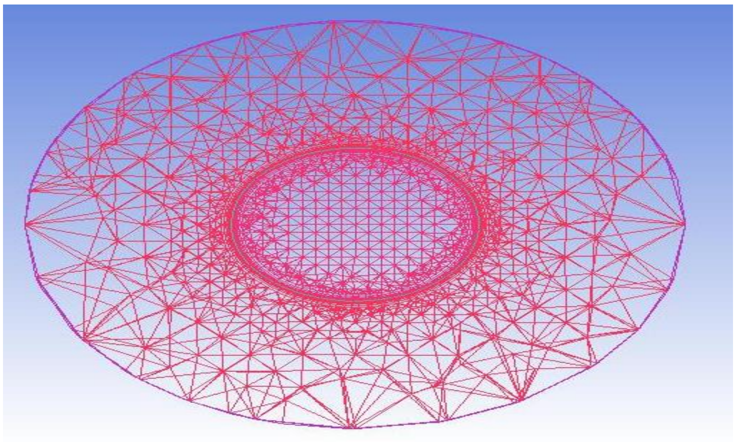

Fig. 3 Meshing of EATHE model

III. RESULT AND DISCUSSION

Grid Independence Study

Performance of computational fluid dynamic analysis at different number of element is called grid independency study. For earth air tunnel heat exchanger model, the grid independence study was done with different number of mesh element i.e. 93750, 1698836, 4954034, 7211741, 9492039 and 12292650.

Table 1 Grid independence study with different number of mesh element

S.no.	Minimum size of element (mm)	Maximum size of element (mm)	Number of element	Outlet temperature of EATHE (°C)
1	0.11	1.5	93,750	31.36
2	0.0275	0.375	16,98,836	32.38
3	0.0157	0.214	49,54,034	32.17
4	0.0129	0.176	72,11,741	32.14
5	0.011	0.15	94,92,039	32.12
6	0.0095	0.13	1,22,92,650	32.12

The computational fluid dynamic analysis outlet temperature result is constant after 94,92,039 number of element. At 94,92,039 number of element the maximum and minimum size of element is 0.15 and 0.011.

So the maximum and minimum element size 0.15 and 0.011 is stander for earth air tunnel heat exchanger model. I have use this standard size sof element for earth air tunnel model for optimization of design, material of tube, tube diameter, air velocity and length of pipe.

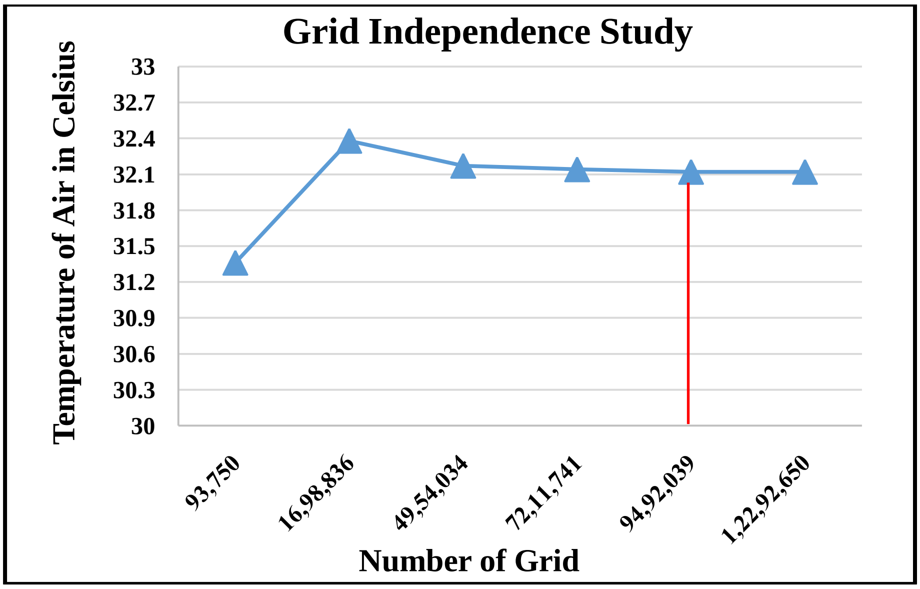

Fig. 4 Graph of grid independency study

Validation of model to experimental data

The CFD based earth air tunnel heat exchanger modelling is validated by taking the observations of an actual earth air tunnel heat exchanger fabricated at Ajmer (Western India). The experimental observations was taken on March 12, 2009 and repeated on April 08, 2009 at Ajmer. The experiment flow of air is made through the material of PVC and steel pipes separately. The two horizontal cylindrical pipes of 0.15 m inner diameter with the buried length of 23.42 m made up of PVC and mild steel pipes and buried at a depth of 2.7 m in a flat land with dry soil. The two pipes viz. PVC and steel are connected to common intake and outlet manifold for air passage. The observations were taken for flow velocities 5 m/s.

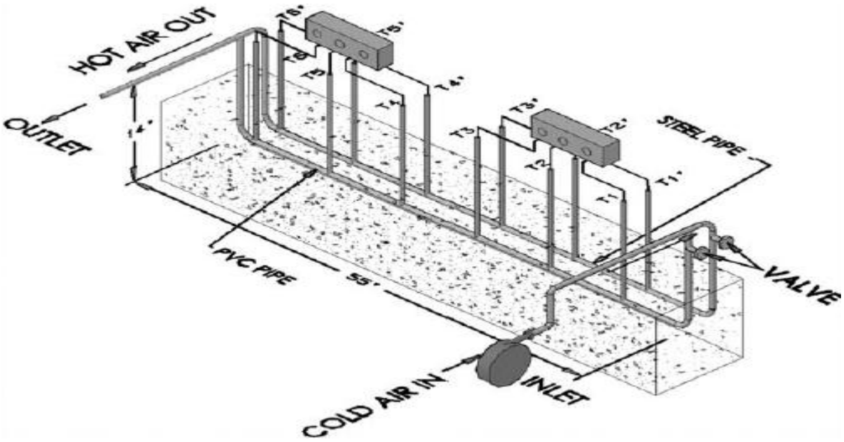

Fig.5 Experimental Set-up of EATHE

Table 2 Physical and thermal parameters used in validation

S.no.	Material	Thermal conductivity (w/m K)	Density (kg/m3)	Specific heat capacity (j/kg K)
1	Air	0.0242	1.225	1006
2	Soil	0.52	2050	1840
3	PVC	0.16	1380	900

Table 3 Comparison of experimental and simulated temperature at different sections along the length

S. No.	Temperature Sensor	Length (m)	Simulation Temperature (^{0}C)	Experimental Temperature (^{0}C)	% Difference
1	T_{inlet}	0.00	42.20	42.20	00
2	T_1	3.34	37.18	39.30	5.39
3	T_2	6.69	35.68	37.90	5.85
4	T_3	10.03	34.73	37.00	6.13
5	T_4	13.38	33.96	36.10	5.92
6	T_5	16.72	32.61	35.30	7.62
7	T_6	20.07	32.42	34.80	6.83
8	T_{outlet}	23.42	32.12	34.20	6.07

Table 3 shows the validation of simulated temperatures with experimental results. The variation in simulation and experimental results are 6.07% at outlet of earth air tunnel heat exchanger. This variation may be take place due to variation in the coefficient of friction of the engineering material which is used in simulation and experiment, irregularities such as joints in experimental set-up and improper insulation at the risers of experimental set-up.

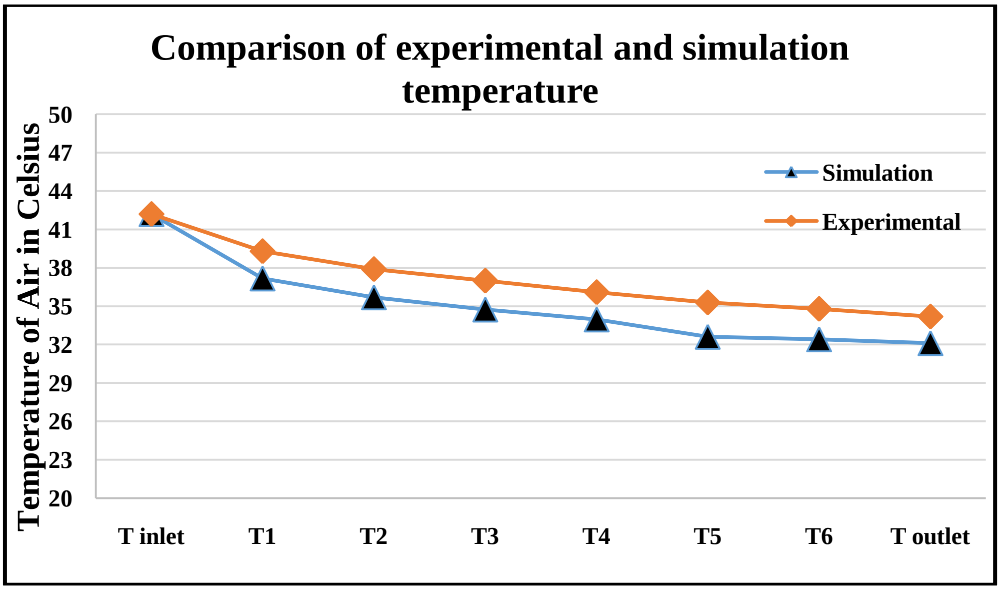

Fig. 6 Graph of validation

IV. CONCLUSION

The computational fluid dynamic analysis earth ait tunnel heat exchanger has been done for validating of CFD model to experimental data. The variation in simulation and experimental results are 6.07% at outlet of earth air tunnel heat exchanger. This variation may be take place due to variation in the coefficient of friction of the engineering material which is used in simulation and experiment, irregularities such as joints in experimental set-up and improper insulation at the risers of experimental set-up.

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