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SOLAR DISTILLATION USING POROUS LAYER

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Abstract - *In the present scenario of water scarcity, anything that will give out pure water cost effectively is the need of the era. In this attempt we propose a model that will increment the rate of generation of pure water from a solar distillation unit. Currently, steam generation using solar energy is based on heating bulk liquid to high temperatures. This approach requires either costly high optical concentrations leading to heat loss by the hot bulk liquid and heated surfaces or vacuum. The proposed model uses a porous double layer structure resulting in the generation of steam at a lower temperature.*

The factors aiding steam generation are mentioned below:-

1) Localization of heat at a point due to low thermal conductivity.

2) Lowering of pressure at the superficial layer of the double layer structure augmenting capillary rise of water.

In this method the porous double layer structure maintains the temperature of the bulk liquid to a very low level. Hence, preventing the loss of energy as heat to the surrounding molecules. The porous double layer structure provides a novel approach to harvesting solar energy for a broad range of phase change applications like effluent water treatment, desalination, sterilization of equipment's etc.

The solar vapor generation has attracted extensive attentions, since energy shortage and water scarcity along with water pollution are becoming alarming global issues to be addressed. The solar vapor generation relies on the performance of the solar absorbers which convert the solar energy into heat for the vaporization process. In the present work we are studying the effect of polyurethane foam for different thickness and carbon foam with graphite flakes immersed in water and subjected to radiation of 10KW/m^2 to study the effect of vapor generation to observe the effect of solar distillation. We are comparing the different cases with the effect of volume fraction of steam generated in the air domain. The simulations were carried out in ANSYS *Fluent 15.0 for the necessary boundary condition.*

1. INTRODUCTION

As the hourly incident solar flux on the surface of earth is greater than annual global energy consumption, solar irradiation is a promising source of renewable energy. The current methods of generating steam using solar energy relies on a surface or cavity to absorb solar radiations and then transfer the heat to the bulk liquid directly or via an intermediate fluid. We report the development of an approach and corresponding material structure for solar steam generation while maintaining low optical concentration and keeping the bulk liquid at low temperature with no vacuum. Here we are doing four experiments, first one is a double layer structure (DLS) consisting of carbon foam and graphite flakes. It is a structure which consists of a carbon foam layer supporting an exfoliated graphite layer.in this structure,97% of irradiated solar power is absorbed within the top exfoliated graphite layer. Solar absorption in the exfoliated graphite layer generates a hot region in the DLS which is explained in the experimental setup. In this, high performance results from four structure characteristics, absorbing in the solar spectrum, thermally insulating, hydrophilic and interconnected pores. This structure provides a novel approach to harvesting so the energy for the broad range of phase change application.

The next experiment we have done is with polyurethane sponge. The abundant waste polyurethane sponges, commonly considered as one of the municipal wastes, can be recycled and converted into valuable resources of environment. Recently solar vapour generation has attracted extensive attentions, since energy shortage and water scarcity along with water pollution are becoming alarming global issues to be addressed. We report that the recycling self-floating black polyurethane sponge are very promising solar absorbing materials which generate water vapour after simple one step strategy for sustainable and practical systems which shows great potential applications. The solar evaporation relies on the development of a key component that is solar absorber, which converts solar energy into heat to vaporise water. The solar evaporation rate of black polyurethane sponge was measured. The evaporation rate of water was recorded by measuring the mass loss as a function of time. The black polyurethane sponge has evaporation rate 3 times compared with pure water evaporation. The evaporation efficiency of black polyurethane sponge at various thicknesses is measured.

The next experiment done is with capillary tubes in the place of polyurethane sponge. In this experiment dips several capillary tubes and the water comes out through

2. EXPERIMENT

2.1 DOUBLE LAYER STRUCTURE

Current methods of generating steam using solar energy rely on a surface or cavity to absorb the solar radiation, and transferring heat into the bulk liquid directly or via an intermediate carrier fluid, which require high optical concentration and suffer from high optical loss and surface heat loss, or vacuum to reduce convective heat loss under moderate optical concentration. The development of an approach and corresponding material structure for solar steam generation while maintaining low optical concentration and keeping the bulk liquid at temperature with no vacuum is reported. Solar thermal efficiency up-to 85% is achieved there. The steam thus generated is usually in thermal equilibrium with the bulk fluid. Recently, Neumann et al. succeed in generation of steam in bulk water with Au nanoparticles with the power of 1000 kw/m^2 consistent with the analysis of phelan et al. on several experiments concluding that Ag NPs with diameter of 20 nm had the lowest threshold intensity for boiling at 2000kw/m^2.in the DLS structure, solar absorption in the exfoliated graphite layer creates a hot region. Higher receiver efficiency can be achieved in larger systems. The evaporation rates of water with the DLS and the single exfoliated graphite layer is measured and after an initial transient period, the evaporation rate reaches a constant value. For pure water, the absorptance is small in the visible range. This small absorptance with the large absorptance in the infrared regime throughout the volume of the water causes an approximately 10 C temperature rise in steady state condition. This temperature rise leads to enhanced evaporation approximately six times compared with dark environment. The DLS structure shows the highest evaporation rate and it is 2.1 and 2.4 times higher than water at 1 and 10 kw/m^2 respectively.

2.2 STEAM GENERATION IN BPU

The recycled black polyurethane sponges for solar vapour generation. Black polyurethane sponge, one kind of three dimensional porous materials, has been widely used as ant seismic packaging materials for transportation in our daily life today. Most of the black polyurethane sponges are abandoned after one time utilisation .in this work, we demonstrate that the recycled polyurethane sponge with porous structure, low thermal conductivity, low mass density to be floating, could behave as an ideal absorber for solar vapour generation. Surface chemical properties are enhanced by a facile dopamine solution for a stirring treatment to achieve the fast dynamic wettability of the BPU sponges for the fluent water supply on the top surface of the absorber. The surface modified PU sponge showed that the evaporating rate increased more than 3.5 times compared to existing natural evaporation process. The solar vapour generation using different solar absorbers, i.e white PU sponge, BPU sponge and SMBPU sponge were measured and compared it with pure water. The sponges with a diameter of 40 mm and a thickness of 10 mm were floated on a water surface in the beaker and opposed exactly at the centre of light beam. The evaporation rate of SMBPU sponge was larger and it was 3.6 times higher compared with pure water under 1kw/m^2 solar illumination.

2.2.1 EXPERIMENTAL SETUP

In the experiment conducted here we use a beaker to collect the water to be purified. Different porous layers like carbon form and graphite flakes, black polyurethane sponge, capillary tubes etc. are kept over the water collected and over which the beam of concentrated sunlight strikes.

 It is based on the principle of capillary rise, the water rises through the porous layer. The pressure on the top layer is lower than atmospheric pressure in order to account for capillary action, thus the steam is generated at lower temperature at lower pressure.

 The other factor that aids generation of steam is the localization of the sunlight. As the porous material has very low thermal conductivity the heat is concentrated on a point rather than being dissipated throughout the material.

2.2.2 DEVELOPMENT OF MODEL

The porous volumetric absorbers are used in this model and they are:-

1. Double layer structure (DLS) consisting of graphite flakes and carbon foam.
2. Black polyurethane (BPU) sponge.
3. Capillary Tubes

Three materials are chosen to study and evaluate the performance of the materials used. Studies are also proposed to find the efficient, reliable and cost effective material among three. A CFD analysis is also conducted to study the evaporation rates of BPU sponge and DLS.

The underlying chapters briefly explain how the study was conducted in different materials

Fig 1 Treatment of sponge after heating the HCL solution

2.2.3 THE FEASABILITY OF STEAM GENERATION

From the experiment it was found that sufficient amount of steam was not produce.

2.3 COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

Gas and liquid flow behaviour is quantified by partial differential equations representing conservation laws for mass, momentum, and energy. Computational fluid dynamics is a branch of fluid mechanics that uses numerical analysis and algorithms to solve fluid flows situations. High-performing computers are used to conduct the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions.

CFD is based on the Navier-Stokes equations. Arising from applying Newton's second law to fluid motion, together with the assumption that the stress in the fluid is the sum of a diffusing viscous term and a pressure term, these equations describe how the velocity, pressure, temperature, and density of a moving fluid are correlated.

The CFD analysis on distillation using porous layer involve the analysis in different cases by considering two materials of different thickness. The rate of steam generation is found out using ansys 15. This approach is to find out the most reliable material for generation of steam and the optimum thickness of the material to be used.

CFD is useful in a wide variety of applications and here we note a few to give you an idea of its use in industry. The simulations shown below have been performed using the FLUENT software. CFD can be used to simulate the flow over a vehicle. For instance, it can be used to study interactions of the propeller or rotor with the aircraft fuselage. The following figure shows the prediction of the pressure field induced by the interaction of the rotor with a helicopter fuselage in forward flight. Rotors and propellers can be represented with models of varying Complexity. The temperature distribution obtained from a CFD analysis of a mixing manifold is shown below. This mixing manifold is part of the passenger cabin ventilation system on the Boeing767. The CFD analysis showed the effectiveness of a simpler manifold design without the need for field testing.

2.3.1 PROBLEM STATEMENT

The air domain, fluid domain and the porous domain are modeled in the ANSYS Design Modeler. The porous domain is assigned in such a way that it is immersed in water and the top surface of the porous domain is at the same level as the water in the beaker. A radiation heat source is placed at the top of the air domain generating a heat flux of 5000w/m^2. The air domain volume is maintained the same as the beaker to reduce the computational cost. The different cases considered for the simulation are as below:

Case:1 Keeping the heat flux constant and varying the thickness of polyurethane foam at 2mm

Case:2 Keeping the heat flux constant and varying the thickness of polyurethane foam at 4mm

Case:3 Keeping the heat flux constant and varying the thickness of polyurethane foam at 7mm.

Case:4 Keeping the heat flux constant and varying the porous domain to graphite plate mounted on carbon foam.

2.3.2 GEOMETRY

The geometry is modeled in such a way that a beaker of diameter 40 mm and depth 60mm is named as the fluid domain. In order to consider the porous domain is immersed in water, a plane is created for the necessary thickness of the porous domain and sliced accordingly and given the name as porous. To see the effect of steam generated a space of air is created the same dimension as the fluid domain.

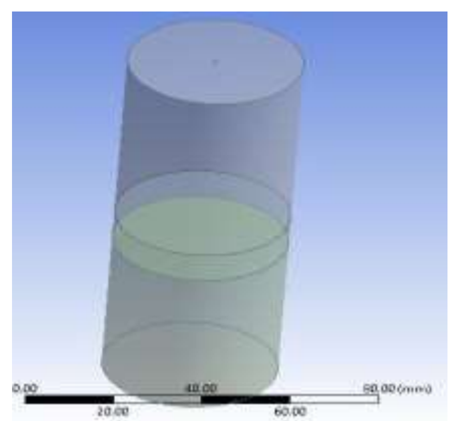


Fig 2. Geometry model of the setup

Interface is assigned to the fluid top, porous bottom, porous top and the air bottom as per the name selection in ANSYS Design Modeler.

The following are the name selection assigned for each domain:

- Beaker walls-The outer walls of the beaker
- Air walls-The outer walls of the air domain
- Heat source-The radiation source of 5000w/m^2 is applied on top.

MESHING

Meshing is the process of dividing the Fluid part into number of infinitesimally small, but non-zero elements. The modeled geometry is meshed in the ANSYS Workbench Mesh module. The solver preference was set as Fluent for the model to be meshed. The relevance was maintained at 0 to get acceptable number of elements for the simulation to be carried out. The total number of elements obtained is 86238 and the skewness is maintained at 0.83 which is acceptable.

Fig 3. Meshed model of the setup

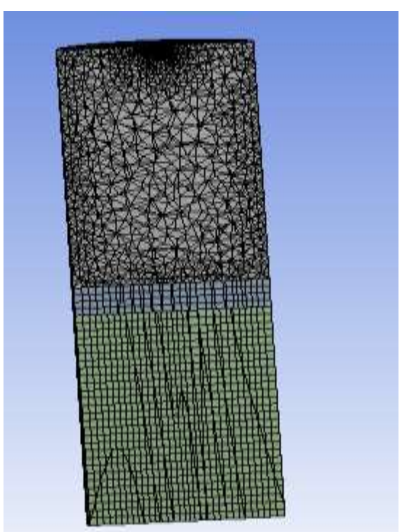


Fig 4. Cut section of the setup

2.3.4 BOUNDARY CONDITION

The computational domain should specify first before specifying the boundary conditions. In this simulation three domains are used. Two fluid domain where the air and water domain are the fluid domain. And the pu-foam/carbon foam is taken as the porous domain. The following are the boundary condition enabled in the simulation:

Model

- Solver Type: Pressure based solver
- Gravity: Enabled (-Z direction)
- Simulation Type: Transient
- Multi-phase: Mixture-Number of phases:3
- Energy: Enabled
- Turbulence: K-epsilon(RNG, Scalable Wall function)
- Radiation:S2S Radiation model

Phases

- Phase-1(Primary Phase):Air
- Phase-2(Secondary Phase):Water
- Phase-3(Secondary Phase):Water Vapour
- Interaction:Phase2-Phase3
- Mechanism-Evaporation-condensation

Cell Zone Condition

- Porous domain-Porosity:0.8

Boundary Condition

Heat Source:5000w/m^2

Outer walls temperature:329K

Mesh Interface

- Air Interface: Interface between the air bottom and porous top
- Water Interface: Interface between the fluid top and porous bottom

Initialization

Hybrid Initialization is done from the given boundary condition.

Adapt:

We have to initialize that water is present in the beaker so we have to give the water volume fraction and the temperature of water by using the adapt.

3. RESULTS AND DISCUSSIONS

4.1 CFD ANALYSIS

CASE 1:- Keeping the heat flux constant and varying the thickness of polyurethane foam at 2mm

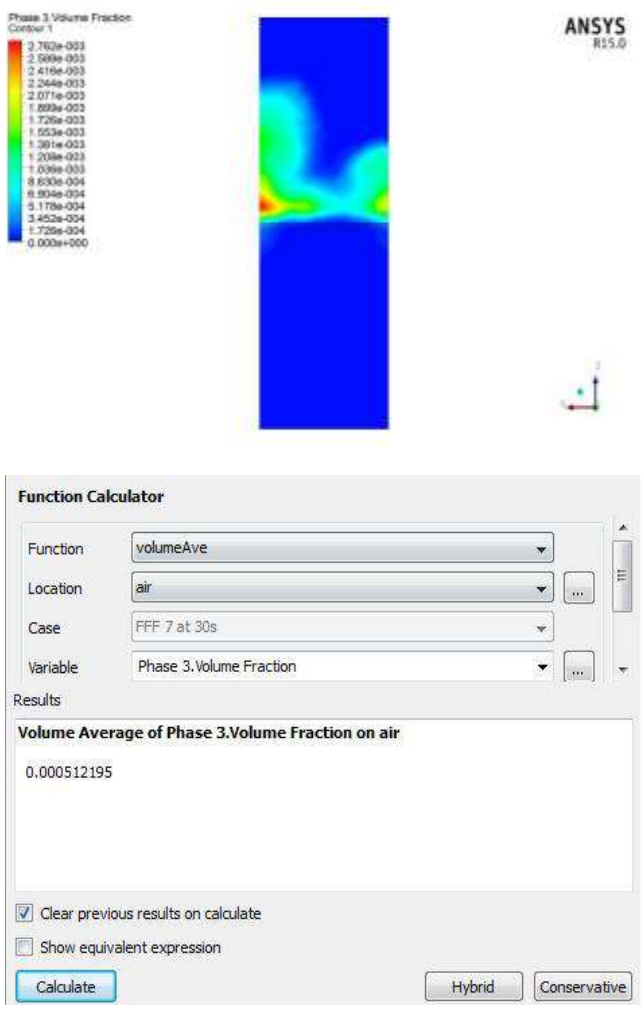
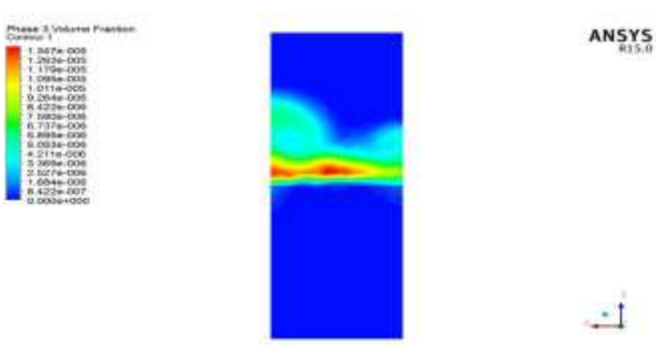


Fig 5. CFD analysis showing the volume fraction of steam while using 2mm BPU sponge

The average volume fraction of steam observed for 2mm thick BPU sponge is 0.000512195

CASE 2 :- Keeping the heat flux constant and varying the thickness of polyurethane foam at 4mm



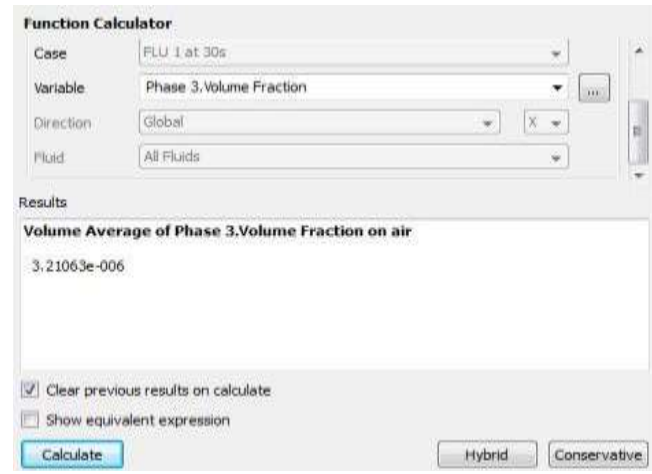


Fig 6. CFD analysis showing the volume fraction of steam while using 4mm BPU sponge.

The average volume fraction of steam observed for 4mm thick BPU sponge is 3.2106*e^-0.006

CASE 3:- Keeping the heat flux constant and varying the thickness of polyurethane foam at 7mm.

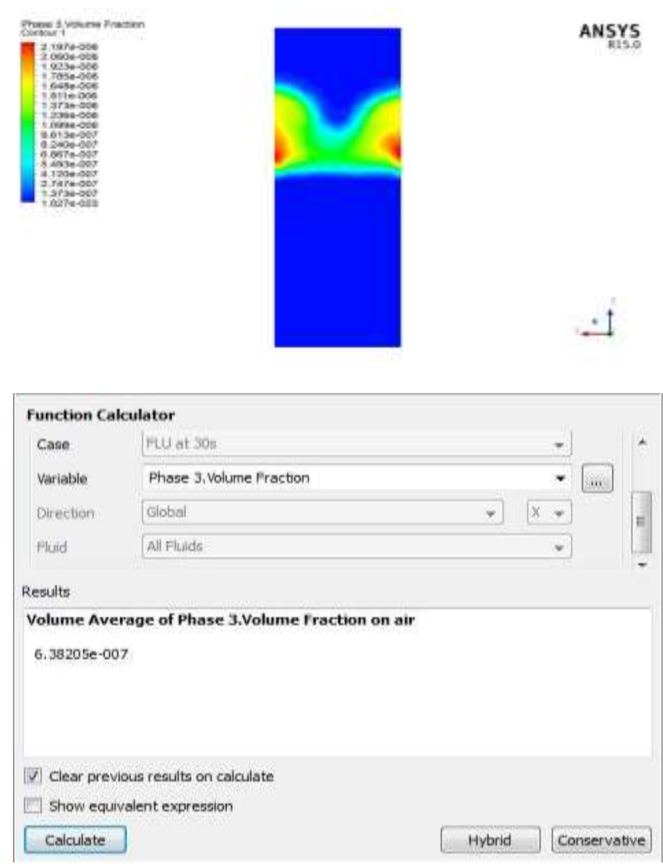


Fig 7. CFD analysis showing the volume fraction of steam while using 7mm BPU sponge

The average volume fraction of steam observed for 7mm thick BPU sponge is 6.38205*e^-0.007

CASE 4:- Keeping the heat flux constant and varying the porous domain to graphite plate mounted on carbon foam.

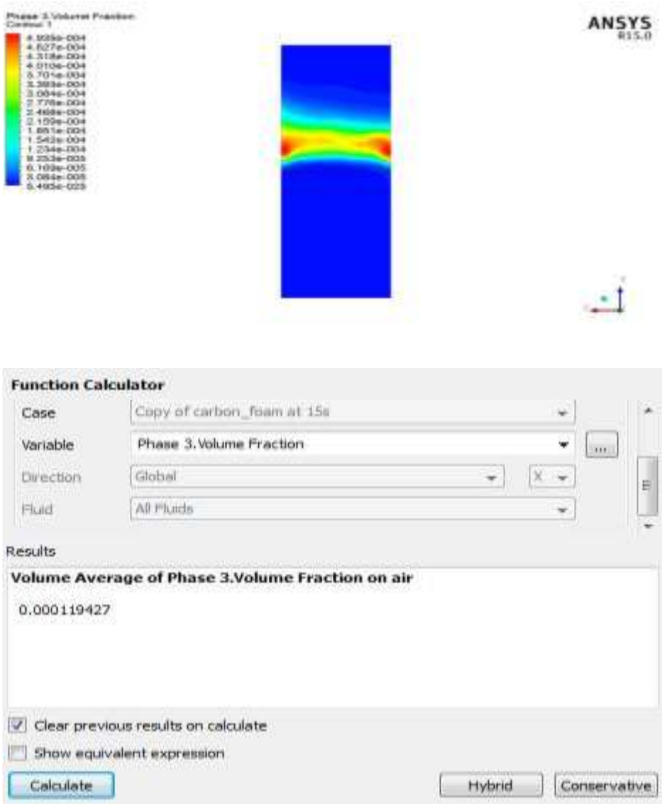


Fig 8. CFD analysis showing the volume fraction of steam while using DLS.

The average volume fraction of steam observed for 2mm thick BPU sponge is 0.000119427

3.1.1PLOTTING TIME VS STEAM VAPOUR FRACTION GRAPH

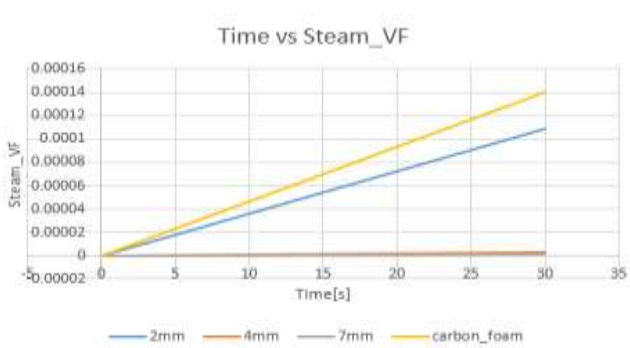


Fig 9. Time vs Steam vapor fraction

The above graph depicts the following results:-

- The DLS gives the maximum volume of steam.
- The 7mm gives the minimum volume of steam

3.2 BLACK POLYURETHANE SPONGE

The experiment was conducted and the graph was plotted between Mass change in grams and Time in seconds.

The experiment was conducted for different optical concentrations like 1Kw/m^2, 2Kw/m^2, 3Kw/m^2 and 5Kw/m^2.

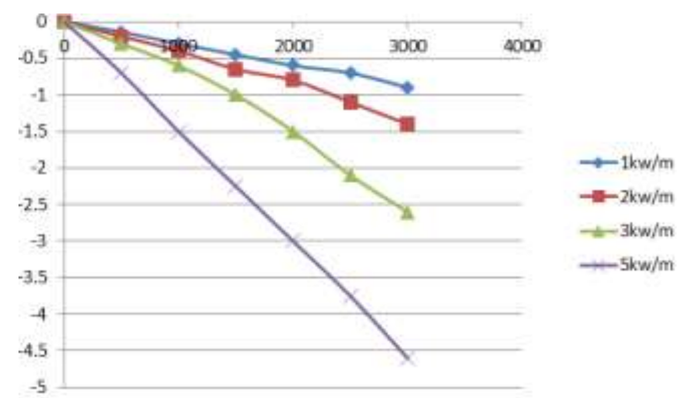


Fig 10. Graph showing time vs vapor fraction at different optical concentrations for bpu.

3.3 DOUBLE LAYER STRUCTURE (DLS)

The experiment was conducted and the graph was plotted between Mass change in grams and Time in seconds.

The experiment was conducted by taking three different cases i.e a comparison made between the evaporation rates of water, water + graphite and water + DLS.

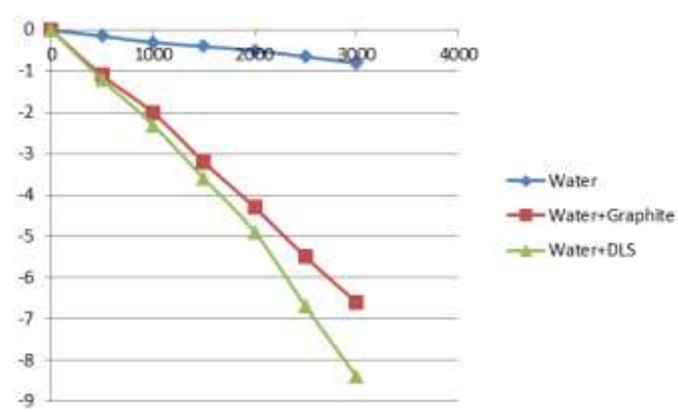


Fig 11. Graph showing time vs vapor fraction at different materials for dls.

4. CONCLUSIONS

The study brings out certain factors which can contribute to the attainment of effective and efficient system which aids in the generation of steam from porous volumetric absorbers. Some facts and findings were found out during our studies which includes the following:-

1. Carbon foam can be made by heating bread to 150°c for 2 hours in a microwave.

2. 0.5M Hydrochloric acid (HCL) can be used to treat sponge instead of dopamine hydrochloride to attain hydrophilicity. But it was found out that the hydrophilicity of the sponge did not last for long.

3. The expected amount of steam vapour fraction was not observed while doing the experiment using BPU sponge. The generated steam was not sufficient to distil some feasible amount of distilled water.

The above mentioned facts denoted the need for a CFD Analysis in order to study more about the generation of steam by using porous volumetric absorbers.

After conducting some studies in CFD on two porous volumetric absorbers (i.e the DLS and BPU) the following facts were concluded:-

1. The DLS showed maximum steam vapour fraction when compared to BPU sponge.

2. Among the BPU Sponge the sponge with thickness of 2mm showed maximum steam vapour fraction when compared to 4mm and 7mm BPU sponge.

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