STUDY OF HEAT TRANSFER IN A SEMI-CYLINDRICAL CAVITY WITH TRIANGULAR VORTEX GENERATOR

Korake Supriya S[1], Dr. Hole J.A[2]
[1,2]Mechanical Engineering Department RSCOE, Tathawade, Savitribai Phule Pune University, Pune – Bombay Highway, Pune- 411038, India .

Abstract: This project aims at Heat transfer in a semi-cylindrical cavity with Triangular Type of Vortex Generator in Various Arrangement . The under laying principle is the phenomenon of natural convection. Natural convection heat transfer from an inclined surface and in cavities is used in various engineering devices .Natural convection heat transfer from an inclined surface and in open cavities are getting more attention due to the importance of such geometry in solar thermal central receiver system. To study heat transfer in semi-cylindrical cavity measurements were carried out on both smooth and rough surfaces for different tilt angles. The results are compared with Triangular Type of Vortex Generator in a tilted semi-cylindrical cavity. Semi-cylindrical cavity is tilted with different angles
Keywords: Natural convection, Heat transfer, Semi-cylindrical cavity, Vortex generators.

I INTRODUCTION

The convective mode of heat transfer involves fluid flow along with conduction, or Diffusion and is generally divided into two basic processes. If the motion of the fluid arises from an external agent, for instance, a fan, a blower, the wind, or the motion of the heated object itself, which imparts the pressure to drive the flow, the process is termed forced convection. If, on the other hand, no such externally induced flow exists and the flow arises "naturally" from the effect of a density difference, resulting from a temperature or concentration difference in a body force field such as gravity, the process is termed natural convection Natural convection heat transfer from an inclined surface and in open cavities are getting more attention due to the importance of such geometry in solar thermal central receiver system. It also helps in aircraft-brake housing system, refrigerators, pipes connecting reservoirs of fluids at various temperatures, fire research, electronic cooling, energy-saving household refrigerators, electronic equipment cooling, etc. Natural convection heat transfer from an inclined surface and in cavities is used in various engineering devices. Natural convection heat transfer from an inclined surface and in open cavities are getting more attention due to the importance of such geometry in solar thermal central receiver system. It also helps in aircraft-brake housing system, refrigerators, pipes connecting reservoirs of fluids at various temperatures, fire research, electronic cooling, energy-saving household refrigerators, electronic equipment cooling, etc. Natural convection heat transfer from an inclined surface and in cavities is used in various engineering devices. Natural convection is sometimes defined as a convective process in which fluid motion is caused by buoyancy effects.

$$q = -kA\left(\frac{\partial T}{\partial y}\right) \quad (1)$$

Where k = Thermal conductivity of the fluid, in W/m^2K

II. DESIGN OF TEST RIG

A. Test Rig

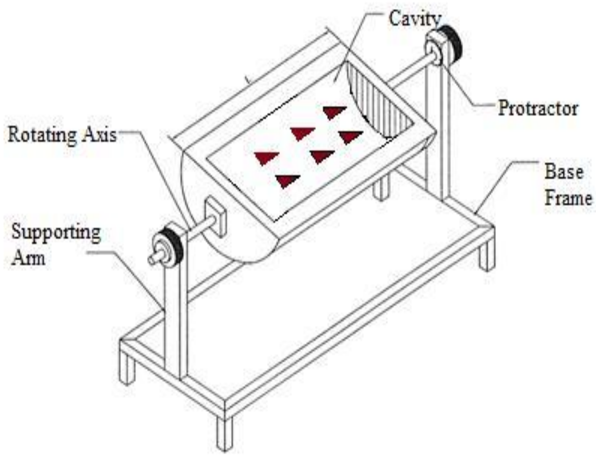

Fig.1 Test Rig with triangular type vortex generators arrangement

The Semi-cylindrical cavity is mounted on a stand. It is supported by two arms. The design of arms and the stand are to minimize the disturbance of the airflow and it will ensure good physical stability. The cavity can be rotated about its longitudinal axis. About the vertical axis the angle of rotation was measured. The semi-cylindrical cavity is made up of aluminium material. The dimensions of cavity are as radius R is of 0.15 m and length l is of 0.9 m and the thickness of cavity is 0.004 mm. The dimensions are chosen in the way that it will give two dimensional flow inside the cavity. The heat is supplied to the cavity by using silicon rubber heaters. The heating pads are self-adhesive and fixed at back of the cavity. Outside of the cavity there are different layers such as first layer is of glass wool of 0.02 m thick, then 0.03 m thick layer of hard polystyrene insulation and then again the 0.02 m thick layer of glass wool is placed at the top. This is a smooth semi-cylindrical cavity.

Fig.2 Actual Experimental Setup

In this experimental set up A triangular type Vortex generators are placed for rough semi cylindrical cavity along the length of cavity with various arrangement with different angles as shown in fig 1& 2. The triangular type vortex generator has l=2h. in this experimental set up l=0.01 m and h=0.005 m. Also in every arrangement they are placed with some angles such as 90^0, 60^0,30^0

Electric circuit and voltage regulator are provided to control heat input. The thermocouples are connected at different point to measure the temperature. All the thermocouples are connected to the digital recorder. The readings are taken at different interval until steady state is reached. The readings were taken at different tilt angles of the cavity at a various positions of Vortex generators and recorded.

B Vortex Generators-

Vortex generators (VG's) are the most commonly known as passive control devices and are already used in different industries. Although VG's come in various shapes and sizes, in general a vortex generator is build up as a small vertical plate positioned at an angle with respect to the local free stream flow.

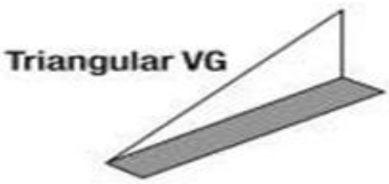

Fig.3 Triangular types of Vortex generators

III. EXPERIMENTAL RESULT AND DISCUSSION

The following readings in this experiment are presented for both smooth and rough semi-cylindrical cavities with triangular vortex type generator. Two semi-cylindrical cavities were tested one with smooth wall and the other with triangular vortex type generator. Nusselt numbers are obtained at different inclination angles 90^0, 60^0,30^0 ,-90^0, 0^0, - 60^0 ,-30^0 for the semi-cylindrical cavity. Different average Nusselt numbers are shown at different angles of inclination of semi cylindrical cavity . The results are carried out for same heat flux value of Q_{total} is 375.5 W/m2.

TABLE 1 Result obtained for both semi cylindrical cavity at 90^0 tilt angle

Sr. No	Time (min)	Smooth Semi cylindrical Cavity			Rough with Triangular type vortex generator Semi cylindrical Cavity		
		Ts (K)	h (W/m^2 K)	Nu	Ts (K)	h (W/m^2 K)	Nu
1	30	480	33.69	36.1	510	39.2	42
2	60	476.5	32.57	34.9	494.6	36.77	39.4
3	90	494	31.82	34.1	508	34.72	37.2
4	120	497.6	29.77	31.9	515	32.76	35.1
5	150	501.1	28.09	30.1	517.5	32.48	34.8
6	180	505.5	28.18	30.2	516	32.01	34.3
7	210	512.3	27.81	29.8	520	31.5	33.8
8	240	518	27.9	29.9	524.6	30.89	33.1
9	270	520.5	27.9	29.9	530	30.98	33.2
10	300	521.2	27.81	29.8	535.4	30.89	33.1
11	330	524	27.81	29.8	531	31.64	33.9
12	360	525.6	27.81	29.8	534.5	31.64	33.9

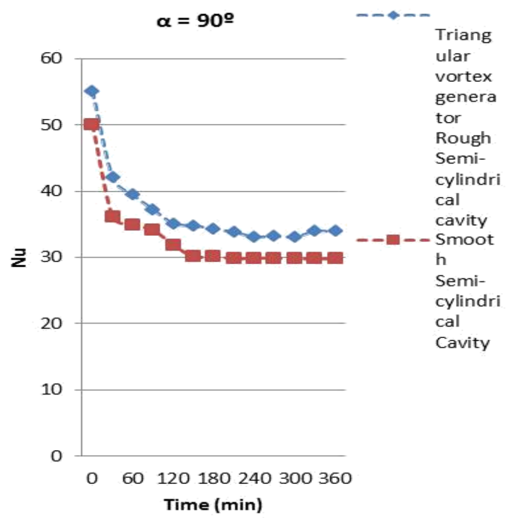

Fig.3.1 Time graph for average Nusselt number at tilt angle of 90^0

Fig. 3.1 Represents the Nusselt number at tilt angle of 90◦. The rough wall with inline vortex generators shows higher value for the average Nusselt number than that of smooth wall of semi-cylindrical cavity. The open part of the cavity is facing down where the buoyancy force is suppressed, allowing heat to be transferred only by molecular conduction through the air enclosed within the cavity. After the steady state time has passed, the air is stratified inside the cavity. The rough wall with triangular vortex type generator shows higher value for the average Nusselt number than that of smooth wall. Graph shows clear difference between Nusselt numbers for Both surfaces . Though there is no convection at this tilt angle Nusselt number shows more on rough surface than smooth surface because of increase in surface area & buoyancy force development.

TABLE 2 Result obtained for both semi cylindrical cavity at 60^0 tilt angle

Sr. No	Time (min)	Smooth Semi cylindrical Cavity			Rough with Triangular type vortex generator Semi cylindrical Cavity		
		Ts (K)	h (W/m² K)	Nu	Ts (K)	h (W/m² K)	Nu
1	30	468.6	32.76	35.1	465	31.73	34
2	60	490.3	30.42	32.6	470.5	27.06	29
3	90	510.0	27.90	29.9	494.2	25.29	27.1
4	120	514.1	25.29	27.1	499.5	23.24	24.9
5	150	520.5	24.17	25.9	508	22.02	23.6
6	180	523.9	23.89	25.6	514.5	21.84	23.4
7	210	529	23.42	25.1	519.6	21.56	23.1
8	240	537	21.56	23.1	509.9	20.62	22.1
9	270	548.6	21.09	22.6	518.1	20.81	22.3
10	300	540	20.90	22.4	525.2	20.72	22.2
11	330	561	21.18	22.7	528.5	20.81	22.3
12	360	570.5	20.72	22.2	533.7	20.62	22.1

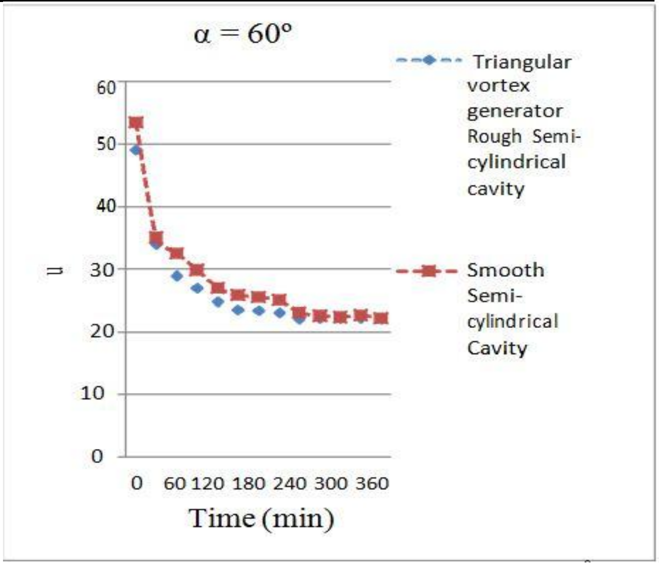

Fig. 3.2 Time graph for average Nusselt number at tilt angle of 60^0

The wall roughness have a large effect on heat transfer inside the semi cylindrical Cavity . Roughness due to inline triangular vortex generators produces drag causing blocking effect to take place resulting in a less heat transfer. Roughness also increases the turbulent intensity on the surface of cavity, which causes heat transfer to increase. Fig. 3.2 Represents the Nusselt number at tilt angle of 60◦,at some time interval Nusselt Numbers at smooth Wall & rough wall are same. It means that buoyancy force is low. at tilt angle of 60◦,the drag produced due to roughness, decreases convection and at some points the smooth wall shows same values for Nusselt nos for the heat transfer over the of the rough wall.

TABLE 3 Result obtained for both semi cylindrical cavity at 30^0 tilt angle

Sr. No	Time (min)	Smooth Semi cylindrical Cavity			Rough with Triangular type vortex generator Semi cylindrical Cavity		
		Ts (K)	h (W/m² K)	Nu	Ts (K)	h (W/m² K)	Nu
1	30	409	39.5	40	411	42.93	46
2	60	426	33.97	36.4	439	36.49	39.1
3	90	441	33.6	36	456	34.81	37.3
4	120	448.6	31.73	34	460.5	33.5	35.9
5	150	449	30.14	32.3	455	31.92	34.2
6	180	454.5	28.93	31	469.9	31.54	33.8
7	210	458.1	29.12	31.2	475.5	30.89	33.1
8	240	460	28.74	30.8	478.6	30.89	33.1
9	270	460.7	28.09	30.1	480.1	30.70	32.9
10	300	448	28	30.0	458	28.18	30.2
11	330	451	27.90	29.9	449	28.37	30.4
12	360	456	27.90	29.9	460	28.37	30.4

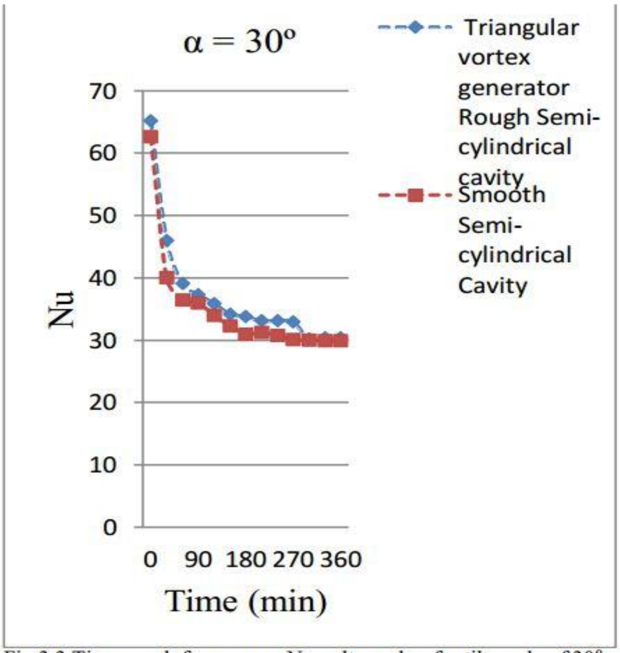

Fig.3.3 Time graph for average Nusselt number for tilt angle of 30^0

At inclination angle 30◦ the heat transfer increased due to the drag produced by the presence of roughness. After some interval of time for angle 30◦, and Nusselt number shows same for both rough and smooth surfaces. So because of blockage effect and turbulence to the flow transfer are same for both.

TABLE 4 Result obtained for both semi cylindrical cavity at 0^0 tilt angle

Sr. No	Time (min)	Smooth Semi cylindrical Cavity			Rough with Triangular type vortex generator Semi cylindrical Cavity		
		T_s (K)	h (W/m² K)	Nu	T_s (K)	h (W/m² K)	Nu
1	30	425	41.25	44.2	420	45.26	48.5
2	60	444.5	39.29	42.1	428	41.34	44.3
3	90	448.5	36.96	39.6	435.5	38.92	41.7
4	120	456.6	35.56	38.1	440.9	37.52	40.2
5	150	460.6	34.81	37.3	446.6	37.05	39.7
6	180	460.9	33.69	36.1	448.1	37.14	39.8
7	210	465.6	33.88	36.3	456	37.05	39.7
8	240	470.2	34.25	36.7	460.1	36.49	39.1
9	270	475.6	34.06	36.5	462.3	36.30	38.9
10	300	478.5	32.94	35.3	467.1	36.30	38.9
11	330	478.1	32.94	35.3	467.1	36.12	38.7
12	360	485.2	32.85	35.2	470.5	35.65	38.2

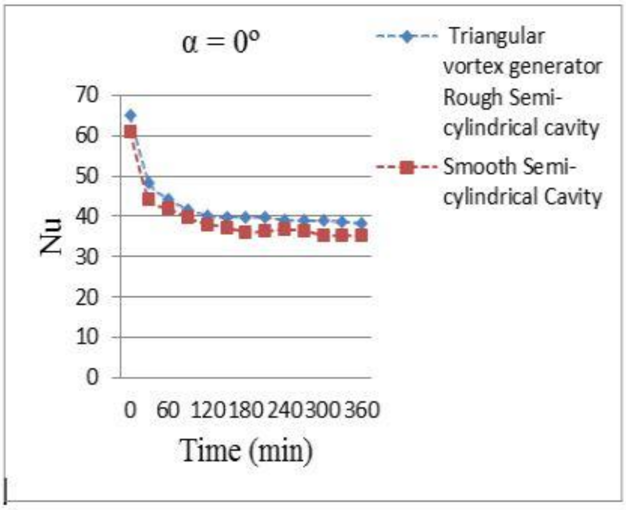

Fig. 3.4 Time graph for average Nusselt number for tilt angle of 0^0

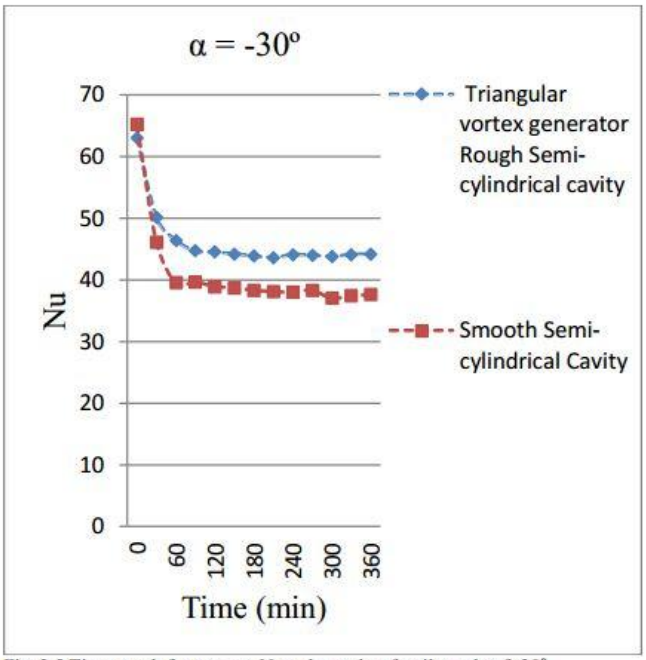

Fig. 3.5 Time graph for average Nusselt number for tilt angle of -30^0

Table 3.5 Result obtained for both semi cylindrical cavity at -30^0 tilt angle

TABLE 5 Result obtained for both semi cylindrical cavity at -30^0 tilt angle

Sr. No	Time (min)	Smooth Semi cylindrical Cavity			Rough with Triangular type vortex generator Semi cylindrical Cavity		
		T_s (K)	h (W/m² K)	Nu	T_s (K)	h (W/m² K)	Nu
1	30	396.5	43.02	46.1	389.5	46.76	50.1
2	60	405.6	36.86	39.5	394	43.30	46.4
3	90	425.1	37.01	39.66	398.5	41.72	44.7
4	120	426.3	36.30	38.9	399.1	41.53	44.5
5	150	428.4	36.12	38.7	404.3	41.25	44.2
6	180	434	35.74	38.3	410	40.97	43.9
7	210	440.1	35.56	38.1	414.5	40.69	43.6
8	240	442.3	35.46	38	415.1	41.16	44.1
9	270	444.5	35.74	38.3	418.6	40.97	43.99
10	300	448.5	34.53	37	419.2	40.88	43.8
11	330	455.5	34.90	37.4	420.1	41.16	44.1
12	360	456.5	35.09	37.6	420	41.25	44.2

Table 6 Result obtained for both semi cylindrical cavity at -60^{0} tilt angle

Sr. No	Time (min)	Smooth Semi cylindrical Cavity			Rough with Triangular type vortex generator Semi cylindrical Cavity		
		Ts (K)	h (W/m^2 K)	Nu	Ts (K)	h (W/m^2 K)	Nu
1	30	428	40.97	43.9	425	43.96	47.1
2	60	433	40.41	43.3	427.5	44.8	48
3	90	435.5	40.13	43	430.1	42.28	45.3
4	120	440.1	40.22	43.1	431.6	41.90	44.9
5	150	443.3	38.26	41.0	430	41.16	44.1
6	180	449.1	38.17	40.9	431.1	41.06	44
7	210	450.3	37.89	40.6	429.8	40.78	43.7
8	240	455.5	37.42	40.1	432.1	40.88	43.8
9	270	458.3	37.24	39.9	436.2	40.32	43.2
10	300	459	36.86	39.5	436.5	40.04	42.9
11	330	460.9	36.58	39.2	437	39.76	42.6
12	360	465.1	36.58	39.2	437.8	39.38	42.2

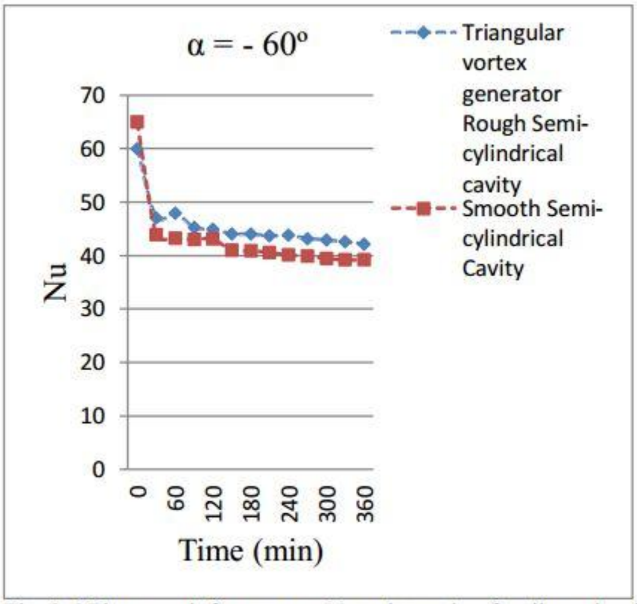

Fig. 3.6 Time graph for average Nusselt number for tilt angle of -60^{0}

From the above readings & graph it shows that at inclination angle of 0◦, −30◦, and −600 are greater for rough surface as compared to smooth surface. The buoyancy force more for these inclination angles. Roughness produced due to triangular type of vortex generator causes the heat transfer to increase over that of the smooth surface for inclination angle 0◦, −30◦, and −600. Also turbulent intensity is increased caused by roughness due to triangular type of vortex generator causes the heat transfer to increase. The dimensions of triangular type of vortex generators are important in boundry layer mechanism which results in increased heat transfer. In these graphs as the tilt angle increases the Nusselts number decreases.

From above all the graphs it shows that the Nusselts number for rough semi cylindrical cavity with triangular type of vortex generators is higher than smooth surfaces.

IV. CONCLUSION

1) The experiment shows the results of heat transfer for smooth as well as rough with triangular type vortex generator semi-cylindrical cavity with different tilt angles such as 90^{0}, 60^{0},30^{0} ,-90^{0}, 0^{0}, - 60^{0} ,-30^{0} Both cavities have the same surface area and the same heat flux.
2) Roughness of surface produces drag causing blockage effect to take place resulting in a less heat transfer. Roughness also increases the turbulent intensity on the surface, which causes heat transfer to increase. Both of each effect is a function of tilt angle
3) When the semi cylindrical cavity is facing down it will gives the minimum value of Nusselt number.
4) The experiment shows that at minimum inclination it will causes increase in heat transfer rate but as inclination increases heat transfer rate increases in average.
5) As the inclination increases heat transfer rate is more for rough semi-cylindrical cavity than the smooth cavity for same inclination angle.
6) The Nusselts number for rough semi cylindrical cavity with triangular type of vortex generators is higher than smooth surfaces.

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