Optimization of Glazing Cover Parameters of a Solar Flat Plate Collector (FPC)

Dhrupad Sarma[1#], Parimal Bakul Barua[2#], Diganta Hatibaruah[3#]

[1] M.E. Student, [2] Professor and H.O.D., [3] Professor

[#]Department of Mechanical Engineering, Jorhat Engineering College, Jorhat, Assam, India

***Abstract*: The goal of this project is to find out the optimum Spacing (Air Gap) of Glazing covers; of Single, Double and Triple Glazed Black painted Flat Plate Collector (FPC) and hence to find out the optimum combination of Number of Glazing and Spacing of Glazing covers(Air Gap) with minimum Top Heat Loss. For that purpose, three 'one factor at a time' experiments were designed for Single, double and triple Glazed FPC, taking Spacing of Glazing cover as variable factor having three levels (5 mm, 10 mm and 15 mm). In the second and third experiment, at each trial condition all the Spacing were kept equal to reduce number of experiment. In total nine prototypes (three for each experiment) were made and experimented simultaneously to cancel out natural variations. All the nine prototypes were exposed to sunlight at the same time and after one hour, stagnation temperature of the prototypes were recorded. The experiments were repeated for seven days. ANOVA for all three experiments were conducted to test the significance of the factor considered in the different cases. The result shows Double Glazed Flat Plate collector with 10 mm Air Gap is the optimal combination for a black painted absorber.**

*Keywords***—Solar Flat Plate Collector, Number of Glazing and Spacing, Top Heat Loss, Stagnation Temperature.**

I. Introduction

Assam, a north-eastern state of India has a sub-tropical monsoon climate. The average rainfall is around 1,500 mm per year. The average daytime temperature in summer is around 35ºC and 25ºC in winter, with a night time minimum of around 10ºC. During the winter season a huge amount of wood is burnt in producing hot water for household purposes. In cities like Guwahati electric water heater are used for the same reason. This need can be fulfilled by solar water heating system. Average solar intensity in Assam is close to 4.5 KWH/m^2/day [1]. To harness this free and abundant energy solar water heating system should be locally produced, as prices of the commercially available system is beyond the reach of common man. Most of the literature found today concentrates on high end technology such as selective coating, vacuum insulated collector tube etc., which requires special setup. Thus the current study concentrates to optimize a solar water heating system which can be made locally here in Assam.

II. LITERATURE REVIEW

In order to find out important factors that affect FPC performance, a series of studies have been made on Solar FPC analysis and optimization. **Lates, R., et al.(2008) [2]** mathematically shows that 83.91% efficiency is achievable with 2mm bottom and side insulation width, 0.1 mm absorber plate thickness, having flow pipes of 30 mm of inner diameter and 49.9 mm of outer diameter with 120 mm spacing between flow pipes. **Ahmad, M. J., et al. (2009) [3]** found that the loss in the amount of collected energy is around 1 % if the angle of tilt is adjusted seasonally instead of using optimum tilt angle for each month of the year. **Farahat, S. et al. (2009) [4]** developed an exergetic optimization model of FPC and found that optical efficiency and inlet fluid temperature has great effect on exergy efficiency of a FPC. **Matuska, T., et al. (2009) [5]** mathematically found that with selective absorber stagnation temperature increases; narrower fin width yields better heat removal; between 40 and 60 mm of frame insulation there is no considerable difference in performance; having tilt angle 90° has least slop impact; Top Heat loss of a FPC with low-emissive absorber (emittance 0.05) is around 75 % of overall collector heat loss. **Eke, A. B., (2011) [6]** experimentally found that if inclination of a FPC set to the predicted optimum angle of inclination for each month of the year, annually the FPC can collect 4.23 % more solar radiation than a horizontal FPC under the same condition. **Ojike, O., (2011)[7]** built and tested a double glazed passive solar collector which is inclined towards the equator at 17°C at Nsukka. The average efficiency found to be 40%. **Agarwal, A., et al. (2012)[8]** found mathematically that changing the tilt angle monthly (i.e. using the monthly-averaged optimum tilt angle) one can receive approximately the same amount of solar radiation that is found by changing the tilt angle daily to its optimum value. A yearly gain in solar radiation of 4.56% can be achieved compared to a solar collector fixed on a horizontal surface. **Bhandari, D. et al. (2012)[9]** concluded that Double glazing single pass solar air heater is found to perform better than with single glazing one. **Badache, M., et al. (2012)[10]** found that on the efficiency of a unglazed transpired solar collector (UTC), absorber coating and the mass flow rate have highest impact than irradiation and air hole diameter. **QinYi, L, et al. (2012)[11]** employed entransy theory to find out the optimum thickness distribution of the absorber with the constraint of fixed total material volume to achieve the optimal heat transfer performance. **Raj, T. K. R., et al. (2012)[12]** tested a FPC with sandwich type collector, the absorber is made of 2 sheets of GI (1 mm) with integrated canals, painted in silica based black paint. The collector is inexpensive and easier to manufacture and results show that the system can reach satisfactory levels of efficiency. **Mintsa Do Ango, A.C., et al. (2013)[13]** found that the polymer

FPSC's length has no effect on the solar collector's performance, optimal air gap found to be 10mm. Increasing the mass flow rate also improves the polymer Flat Plate Solar Collector's (FPSC) efficiency. The incoming solar radiation has a small influence on a collector's efficiency. **Sarma, D., et al (2014) [14]** designed and evaluated a FPC with modified back insulation and achieved 54.3% overall efficiency.

III. OBJECTIVE OF PRESENT WORK

The objective of the present work is to find the optimum Spacing of glazing covers of Single, Double and Triple Glazed Flat Plate Solar Collector (FPC) with black painted absorber. Also the second objective of this work is to find the optimal number of Glazing cover for the same FPC.

IV. METHODOLOGY

In already published literature it is found that 75% of the total heat loss occurs from the front side of a FPC [5]. The main design factors associated with the Top heat Loss are: No of glazing, Air gap, Absorber coating, Material of the glazing and Thickness of the glazing. Out of these factors the following two factors viz., (a) *Number of Glazing* and (b) *Air Gap* are chosen for the current study.

Three experiments were designed to find out best Spacing of Glazing covers (Air Gap) for Single, Double and Triple Glazed FPC. The variable factor in all these three experiments was Spacing of Glazing covers (Air Gap) with three levels (5 mm, 10 mm, 15 mm). The details of these three experiments are given below:

Experiment I:

No. of Glazing: 1 (Constant factor)

Variable factor: Air Gap (5mm, 10mm, 15mm)

TABLE 1: ONE FACTOR AT A TIME ARRAY FOR EXP. I.

Trial No./Prototype No.	Air Gap, mm
1	5
2	10
3	15

Experiment II:

No. of Glazing: 2 (Constant factor)

Variable factor: Air Gap (5mm, 10mm, 15mm)

Here Spacing between first Glazing and Absorber (1st Air Gap) is kept equal to Spacing between second Glazing and first Glazing (2nd Air Gap) and termed as Air Gap, i.e.

Air Gap = 1st Air Gap = 2nd Air Gap

TABLE 2: ONE FACTOR AT A TIME ARRAY FOR EXP. II.

Trial No./Prototype No.	Air Gap, mm	
	1st Air Gap	2nd Air Gap
1	5	5
2	10	10
3	15	15

Experiment III:

No. of Glazing: 3 (Constant factor)

Variable factor: Air Gap (5mm, 10mm, 15mm)

Where,

Air Gap = 1st Air Gap = 2nd Air Gap = 3rd Air Gap

Here 3rd Air Gap is the spacing between the third and second Glazing covers.

TABLE 3: ONE FACTOR AT A TIME ARRAY FOR EXP. III.

Trial No./Prototype No.	Air Gap, mm		
	1st Air Gap	2nd Air Gap	3rd Air Gap
1	5	5	5
2	10	10	10
3	15	15	15

In total nine prototypes were made, one for each of the trial condition. All the other factors listed in Table: 4 are kept constant in all the prototypes. The performance criteria chosen here is the *Stagnation temperature** of the absorber plate. Here it is assumed that higher the Stagnation temperature, lower is the Top heat loss (Side and Back insulation being same in all the prototypes), or better the optical performance. All the nine prototypes experimented simultaneously under normal daylight. The Stagnation temperature of the absorber plate after one hours of exposure to sunlight is measured. All the nine prototypes were experimented simultaneously to cancel out effect of variation in solar radiation during experiment.

* Stagnation Temperature: It is the steady state temperature of the absorber plate when there is no mass flow (no heat withdrawal).

The experiments were run for seven days to cancel out experimental error. The list of factors associated with the prototypes is summarised in Table: 4 (ANNEXURE).

V. PROTOTYPE CONSTRUCTION DETAILS:

The construction of the various components of the prototypes is discussed below. A cross sectional view of a double glazed prototype is shown in Fig. 1.

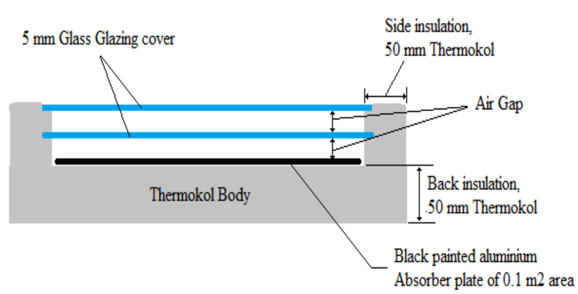


FIG. 1: A CROSS SECTIONAL VIEW OF A DOUBLE GLAZED PROTOTYPE.

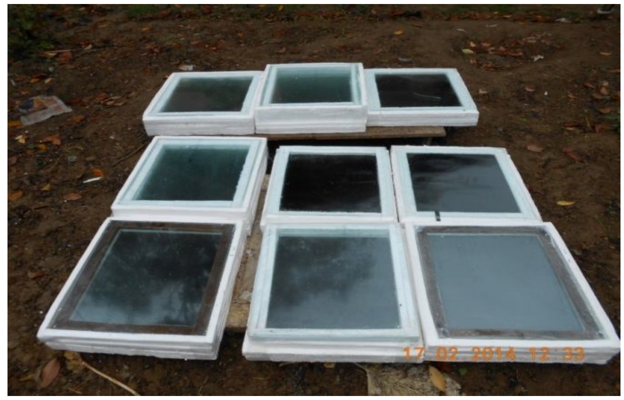
***Insulation and Enclosure*:** In FPC insulation glass wool is preferred as it has good insulation properties. Glass wool also has good durability and is stable in wide range of temperature. But glass wool insulation requires outer enclosure as it lacks mechanical strength. So in our prototype we choose thermocol over glass wool. Thermocol sheets are easy to cut and glue to desired shape, it has better mechanical strength then glass wool and has thermal conductivity almost equal to glass wool. Thermal conductivity of glass wool is 0.04 W/m-K and of thermocol is 0.03 W/m-K. Thus glass wool can be replaced by thermocol for same insulation thickness in our experiment. It can give same thermal resistance to heat flow. In our prototypes thermocol insulation itself acts as enclosure to the absorber plate and glazing panels. A 50 mm of back and side insulation is applied in the prototypes. To protect the thermocol from high temperature absorber plate, a 5 mm thick wooden board is placed between the absorber plate and thermocol body.

***Absorber plate*:** The absorber plate is made of 1 mm Aluminium sheet of 300 mm x 340 mm size. To keep the cost minimum, absorber area is chosen to be 0.1 m^2. To keep the aluminium sheet perfectly flat a 5 mm wooden board of same size attached to it by means of board pins. The front of the aluminium sheet is painted with commercially available black paint. As we are interested to find out the stagnation temperature only, no arrangement for coolant flow has been added to the absorber plate. The average mass of the aluminium sheet is found to be 80 gm.

***Glazing and Glazing frame*:** Low iron clear glass of 5 mm thickness is used as glazing panel for the prototype. To maintain the air gap between the absorber and glazing or the air gap between glazings, frame made of thermocol is used. To give it added strength the frame is warped with transparent self-adhesive tape.

VI. EXPERIMENTAL SETUP

All the nine prototypes were kept in a horizontal (angle of tilt 0°) plane using a level gauge. The prototypes were exposed to sunlight at 9.00 AM and after one hour, temperature of all the prototypes were measured using a digital thermometer (Range: -50°C to +300°C, Accuracy: ±0.5°C) and recorded. At that time the atmospheric temperature is also recorded with the same thermometer. The experiments were run for seven days to cancel out temperature reading error. Experiments were performed in Jorhat Engineering College campus, Jorhat, Assam in the month of February 2014. The Pic.1 below show the field setup of the prototypes.



PIC.1: FIELD SETUP OF PROTOTYPES

VII. RESULT & DISCUSSION

Result of all the three experiments are analysed with standard ANOVA procedure to determine, wheatear the variance in stagnation temperature is due to chance factor or due to change in level of the variable factor (Air Gap). Next a graph is plotted for each experiment, taking average stagnation temperature in vertical axis and Air Gap level in horizontal axis. The graph (Main effect plot) shows the optimum level of the Air Gap for each experiment. Experimental results (Table 5, 7, 9) are shown in ANNEXURE with their ANOVA table (Table 6, 8 and 10). The Main effect plot of each experiment is given below:

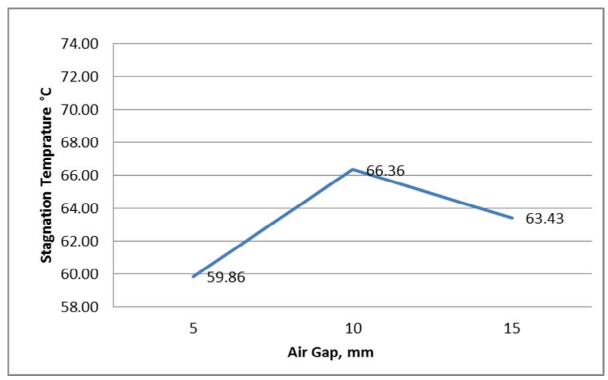


FIG 2: MAIN EFFECT PLOT OF EXP. I

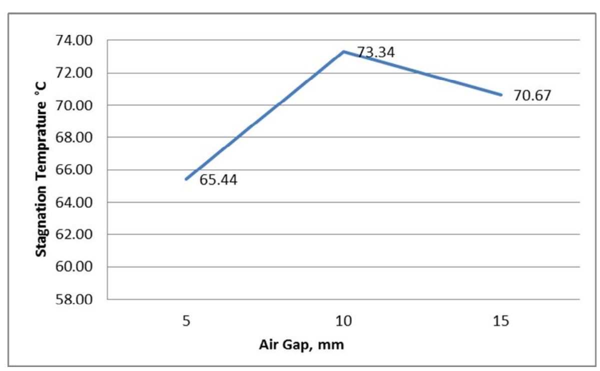


FIG 3: MAIN EFFECT PLOT OF EXP. II

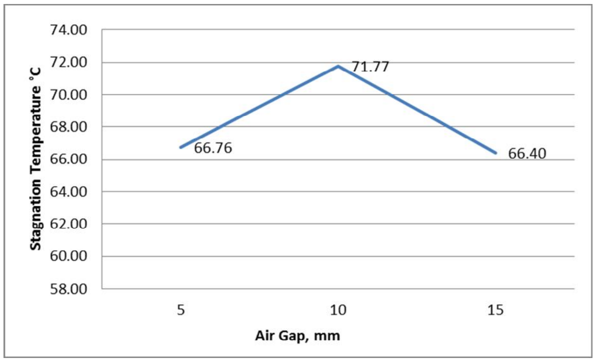


FIG 4: MAIN EFFECT PLOT OF EXP. III

From ANOVA analysis it can be seen that, in all the experiments calculated F value for the Air Gap is higher than tabulated F value at 95% confidence level. Thus it is clear that Air Gap has a strong influence on the performance of a FPC with black painted absorber.

From Main effect plot of Air Gap (Fig 2, 3 and 4), it is seen that in all the three experiments 10 mm Air Gap gives the maximum stagnation temperature. In all the three cases as Air Gap increases from 5mm to 10 mm, Stagnation temperature also increases. When the Air Gap further increases to 15 mm, Stagnation temperature decreases. The Optimum Air Gap value found in this experimental setup is in line with already published literature [13]. The air trapped inside the Air Gap acts as an insulator and reduces heat loss. As the Air Gap increased from 5mm to 10 mm, thickness of this air insulation increases, thus conduction heat loss through this air insulation decreases. When Air Gap is further increased to 15 mm, a convection current sets up inside the Air Gap due to difference in temperature between the absorber and first glazing cover. This convective heat loss dominates conductive heat loss at 15 mm Air Gap, thus Top heat loss increases at this level.

The average Stagnation temperature at optimum level of each experiment is summarised in Table 11.

TABLE 11: RESULT SUMMERY

Experiment No	No of Glazing	Optimum Air Gap	Avg. Stagnation temp. at optimum
I	1	10 mm	66.36 °C
II	2	10 mm	73.34 °C
III	3	10 mm	71.77 °C

From Table 11, it can be seen that when Number of glazing is increased from 1 to 2 Nos. (Keeping same Air Gap); Stagnation temperature increases, indicating decrease in Top heat loss. With three Glazing the Stagnation temperature slightly decreases. Actually when an additional Glazing cover is added over a Single Glazed FPC, that second glazing acts as an additional barrier to Top heat loss and thus absorber temperature increased. But each Glazing cover also reduces incoming solar radiation by reflection and absorption. Thus with a third Glazing these losses increases and absorber temperature slightly decreases.

VIII. CONCLUSION

In the present work optimal Spacing of Glazing covers (Air Gap) of a black painted FPC is determined experimentally. Three experiments were designed to find out optimal Air Gap for Single, Double and Triple Glazed FPC. At each experiment Air Gap varied at three level viz. 5mm, 10mm and 15 mm. During the experimentation Air Gap of each Glazing cover is kept equal within a trial condition to reduce number of trial. From the analysis of the result the following conclusion can be drawn:

Optimum Spacing of Glazing cover is 10 mm for Single, Double and Triple Glazed FPC.

Among all the prototypes (trial conditions), the prototype having double glazing with 10 mm Air Gap shows maximum Stagnation temperature.

In the present work, effect of changing the Air gap of each Glazing of a double and triple glazed FPC has not been studied. Hence a study should be made to find out the effect of Air Gap of each Glazing cover on the performance of a FPC.

ACKNOWLEDGMENT

The authors wish to acknowledge with a deep sense of gratitude the help and guidance solicitously given to us by the faculty members of Department of Mechanical Engineering, Jorhat Engineering College, Assam.

We also extend our gratitude to Mr. Kiron Hazarika, Garmur, Jorhat for helping us in prototype fabrication.

REFERENCES

[1] NASA, Atmospheric Data Center, Available at: https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi

[2] Raluca Lates, Ion Visa and Ciprian Lapusan, "Mathematical optimization of solar thermal collectors efficiency function using MATLAB", *4th IASME/WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development (EEESD'08)*, Algarve, Portugal, June 11-13, 2008.

[3] M. Jamil Ahmad and G.N. Tiwari, "Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation", *The Open Renewable Energy Journal*, 2, pp. 19-24, 2009.

[4] S. Farahat, F. Sarhaddi and H. Ajam, "Exergetic optimization of flat plate solar collectors", *Renewable Energy*, 34, pp. 1169–1174, 2009.

[5] Tomas Matuska, Vladimir Zmrhal and Juliane Metzger, "Detailed modelling of solar flat-plate collectors with design tool kolektor 2.2", *Eleventh International IBPSA Conference*, Glasgow, Scotland, July 27-30, 2009.

[6] Akachukwu Ben Eke, "Prediction of optimum angle of inclination for flat plate solar collector in Zaria, Nigeria", *Agricultural Engineering International: CIGR Journal*, vol. 13 (4), pp. 1840, 2011.

[7] O. Ojike, "Characterization of a flat plate double glazed solar collector", *Continental J. Renewable Energy*, vol. 2 (2), pp. 10 – 18, November 2011.

[8] Abhishek Agarwal , Vineet Kumar Vashishtha and Dr. S.N. Mishra, "Comparative approach for the optimization of tilt angle to receive maximum radiation", *International Journal of Engineering Research & Technology (IJERT)*,vol. 1(5) ,July 2012.

[9] D. Bhandari and Dr. S. Singh, "Performance analysis of flat plate solar air collectors with and without fins", International *Journal of Engineering Research & Technology (IJERT)*, vol. 1(6), August 2012.

[10] Messaoud Badache, Ste´phane Halle´ and Daniel Rousse, "A full 3^4 factorial experimental design for efficiency optimization of an unglazed transpired solar collector prototype", *Solar Energy*, vol. 86, pp. 2802–2810, July 2012.

[11] LI QinYi and Chen Qun, "Application of entransy theory in the heat transfer optimization of flat-plate solar collectors", *Chinese science bulletin*, vol. 57(2-3), pp. 299-306, January 2012.

[12] Raj Thundil Karuppa R., Pavan P. and Reddy Rajeev D., "Experimental Investigation of a New Solar Flat Plate Collector", *Research Journal of Engineering Sciences*, vol. 1(4), pp. 1-8, October 2012.

[13] A.C. Mintsa Do Ango, M. Medale and C. Abid, "Optimization of the design of a polymer flat plate solar collector", *Solar Energy*, vol. 87, pp. 64–75, 2013.

[14] D. Sarma , R. Gogoi , B. Nath , S. Konwar and C.L. Meitei, "Design, Fabrication and the Experimental Performance Evaluation of Flat Plate Solar Water Heater specifically for Jorhat, Assam (26.75°N, 94.22ºE)", International Journal of Engineering Trends and Technology (IJETT), vol. 12 (7), pp. 341-352, June 2014.

ANNEXURE

TABLE 4: LIST OF FACTORS ASSOCIATED WITH THE PROTOTYPES

Sl. no	Factor	Range/value	Type	Comment
1	Tilt angle	0°	Constant	Horizontal
2	Mass flow (Mass)	0, Mass of the Al plate (80 gm)	Constant	No heat withdrawal, No mass flow
3	Incident solar flux	4.5 KWH/m^2/day [1]	Natural Variable	Noise
4	Bottom insulation thickness	50 mm	Constant	Thermocol
5	Edge insulation thickness	50 mm	Constant	Thermocol
6	Absorber Coating	Black paint	Constant	Cheap, Easily available
7	No of Glazing	1-2-3 nos.	Exp. I= 1 No Exp. II=2 Nos Exp. III=3 Nos	Material: 5 mm low iron glass
8	Air Gap thickness	5-10-15 mm (3 level)	Variable	At Atmospheric pressure

TABLE 5: EXPERIMENTAL DATA OF EXPERIMENT I.

Trial No.	Air Gap, mm	Stagnation Temperature °C							Average °C
		R1	R2	R3	R4	R5	R6	R7	
1	5	59.3	60.1	60	60.7	61.2	58.4	59.3	59.86
2	10	65.3	67.1	66.5	67.6	68.4	64.6	65	66.36
3	15	62.5	63.3	64	65.2	65.5	61.1	62.4	63.43

Where R1, R2… R7 are the repetition number.

TABLE 6: ANOVA TABLE OF EXPERIMENT I.

Source	DF	SS	MS	F	SS’	P	F(0.05) Tabulated	Comment
Air Gap	2	148.357	74.179	40.722	144.714	79.888	3.555	Significant
e	18	32.789	1.822	1	36.432	20.112		
Total	20	181.146	76.000			100		

Where,
DF = Degree of Freedom, SS = Sum of Square, MS = Mean Sum of Square, F = F value or Variance ratio
SS’= Pure Sum of Square, P = Percentage contribution, F (0.05) Tabulated = Tabulated F value with 95% confidence, e = Error

TABLE 7: EXPERIMENTAL DATA OF EXPERIMENT II.

Trial No.	Air Gap, mm	Stagnation temperature °C							Average °C
		R1	R2	R3	R4	R5	R6	R7	
1	5	65.1	65.6	65.6	66	66.4	64.1	65.3	65.44
2	10	73	73.7	73.2	74.1	74.5	72.3	72.6	73.34
3	15	70.4	71	70.5	71.2	71.8	70	69.8	70.67

TABLE 8: ANOVA TABLE OF EXPERIMENT II.

Source	DF	SS	MS	F	SS’	P	F(0.05) Tabulated	Comment
Air Gap	2	226.064	113.032	203.283	224.952	95.289	3.555	Significant
e	18	10.009	0.556	1	11.121	4.711		
Total	20	236.072	113.588			100		

TABLE 9: EXPERIMENTAL DATA OF EXPERIMENT III.

Trial No.	Air Gap, mm	Stagnation Temperature °C							Average °C
		R1	R2	R3	R4	R5	R6	R7	
1	5	66.3	67.1	66.8	67.6	68.1	65.3	66.1	66.76
2	10	71.4	72.3	72	72.6	72.5	70.5	71.1	71.77
3	15	66	67	66.5	66.8	67.7	65	65.8	66.40

TABLE 10: ANOVA TABLE OF EXPERIMENT III.

Source	DF	SS	MS	F	SS’	P	F(0.05) Tabulated	Comment
Air Gap	2	126.287	63.143	82.055	124.748	89.018	3.555	Significant
e	18	13.851	0.770	1	15.390	10.982		
Total	20	140.138	63.913			100		