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AN EXPERIMENTAL STUDY ON REJECTION OF AIR INSIDE A BUS BY MEANS OF HIGH RATE OF VORTICITY AROUND THE VEHICLE

Serkan MEZARCIÖZ
Temsa Global San. ve Tic. A.Ş. R&D Division. Adana/Türkiye

Ahmet PINARBAŞI, Beşir ŞAHİN
Ç.Ü., Makine Mühendisliği Bölümü, Adana

ABSTRACT : *Rejecting the humid air inside vehicles is important for both refreshment of air inside vehicles and for preventing fog formation on the windshield. In this study a natural air rejection system utilizing the high rate of vorticity created by the flow around the vehicle is designed and being tested under different vehicle speeds and air conditioner fan speeds. Firstly a numerical study is conducted to determine the most proper high vorticity region of the vehicle with the commercial computer code FLUENT and than by considering the analysis results and vehicle structure, the most proper regions are determined as over the front door and driver window. In the experiments, an air intake box equipped with an electrical flow control flap is installed over the front door of a 12,2m long coach and the air rejection speeds are measured. The test results showed that the air rejection speed is directly proportional to the vehicle speed, and the relationship between them is linear.*
Anahtar kelimeler: *Natural ventilation, air rejection, vorticity, bus ventilation, mist*

OTOBÜS İÇİNDEKİ HAVANIN, ARAÇ ETRAFINDAKİ YÜKSEK GİRDAP ORANI ARACILIĞI İLE TAHLİYE EDİLMESİ ÜZERİNE DENEYSEL BİR ÇALIŞMA

ÖZET : *Araç içindeki nemli havanın dışarı atılması, hem araç içindeki havanın tazelenmesi hem de ön camda buğu oluşumunu önlemesinden dolayı çok önemlidir. Bu çalışmada araç etrafındaki akışın oluşturduğu yüksek girdap oranından yararlanan doğal bir havalandırma sistemi tasarlanıp, değişik araç hızları ve klima fan hızları altında test edilmiştir. Öncelikle aracın en uygun yüksek girdap bölgesinin belirlenmesi için ticari bir bilgisayar programı olan FLUENT ile nümerik bir çalışma yapılmış ve bunun ardından analiz sonuçları ve aracın yapısı göz önüne alınarak en uygun yer olarak ön kapının ve sürücü penceresinin üzeri belirlenmiştir. Deneylerde, elektrikli akış kontrol klapesine sahip bir hava emiş kutusu, 12,2 m uzunluğunda şehirlerarası yolcu otobüsünün ön kapı üzerine monte edilmiş ve hava tahliye hızları ölçülmüştür. Test sonuçları göstermiştir ki; hava tahliye hızı ile araç hızı doğru orantılıdır ve aralarındaki ilişki doğrusaldır.*
Keywords: *Doğal havalandırma, hava tahliyesi, girdap, otobüs havalandırması, buğu.*

1. INTRODUCTION

Rejecting the humid air inside the vehicles is very important for both refreshing the air inside the bus to provide a comfortable media for the passengers and preventing the fog formation on the windshield in the winter times. Rejecting the impure and humid air can be done by using an aspirator equipped with a motor fan or a natural system utilizing the high rate of vorticity created by the flow around the vehicle. In this study instead of a fan system, a natural system is focused on.

A challenging problem faced in the winter times for the drivers is the formation of fog on the windshield of the vehicles. Formation of fog generally creates both the problem of poor vision area for the driver and dangerous situation while the progress of cleaning the fog on the glass. The defrosting systems used in the vehicles generally are not good enough to solve the fog problem individually so rejecting the humid air inside the vehicle has a great importance for the fog formation point of view.

At the same temperature, as the relative humidity of the air decreases, the dew point decreases. So decreasing the relative humidity by ventilation plays an important role on fog formation mechanisms. In Figure 1, the graph of the dew points, calculated based on Magnus-Tetens Approximation (1974), at different ambient temperatures and relative humidity, is shown.

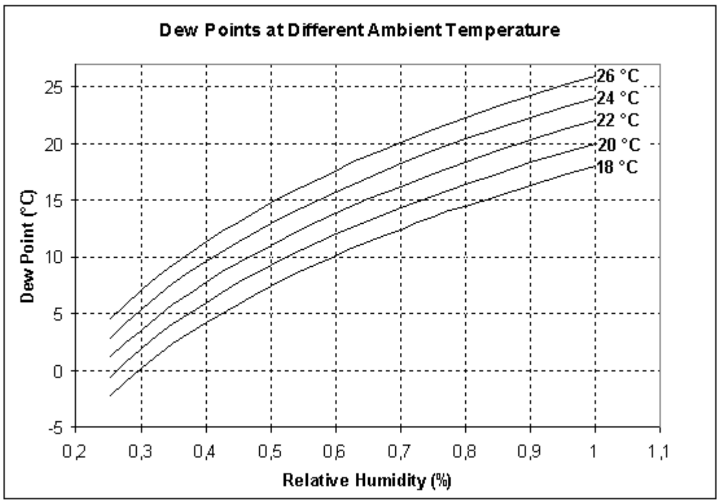

Figure 1. Dew points at different ambient temperatures and relative humidity.

Rejection of the impure air inside the vehicle is important for not only preventing the poor vision area for the driver because of the fog formation on the windscreen, but also providing a fresh air for the maximum healthy and comfortable conditions.

As the air inside a closed media is used, it loses the natural mixture ratio of oxygen and it gets far away from the comfort conditions for the people. In these situations, if temperature rises, perspiration problem occurs. If humidity rises, insufficient skin respiration problem occurs. And if the amount of oxygen inside the air is low, the insufficient respiration and similar problem starts. If the required amount of oxygen for the normal respiration cannot be satisfied, the following events occur; the speed of the respiration, blood circulation and blood pressure increases, headache and symptom of exhaustion starts. These symptoms are created by the lower values of 21% of oxygen inside the air. The solution is to increase the percentage of oxygen to 21% again. The simplest way to restore the natural amount of air oxygen inside the closed media is to make ventilation by rejecting the impure air to the outside and suctioning the fresh air having a high amount of oxygen into the system.

In this study, the fresh air requirement of the vehicle is supplied by the A/C unit, and the defroster, and a natural system to reject the impure air is designed and tested.

2. PREVIOUS STUDIES

Since the flow around the vehicles and ventilation are the most important subjects in the automotive industry, lots of research and studies are performed on these subjects. Especially the subject of fog formation on the windscreen of the vehicles is studied experimentally and numerically.

In the study conducted by Urbank et. al. (2001), an integrated dew point and glass temperature sensor is designed to control the HVAC system of an automobile, to prevent the fog formation on the windshield.

In a similar study conducted by Park et. al. (2007) the development of a control device for automatically demisting windscreen glass is investigated. Automatic demisting control is initiated when the surface temperature of the glass is lower than the dew point temperature at a given relative humidity and temperature of the cabin inside.

Aroussi and A.Hassan (2003) performed computational and experimental studies to compare the side window defrosting performance and demisting mechanisms of several current model vehicles. The experiments are carried out by using full scale current vehicle models. The computational study, whics is validated by the experiments, is used to perform parametric investigation into the side window defroster’s performance.

The flow around the vehicles is also investigated by lots of researchers. Krajnovic and Davidson (2001), investigated two large eddy simulation of the flow past a bus-like vehicle body, and they compared the results with the experimental data of E.G. Duell and A.R. George (1999).

In the study of conducted by Cheng et al. (2003), a fully developed turbulent flow over a matrix of cubes has been studied using the large Eddy simulation (LES) and Reynolds-averaged Navier–Stokes (RANS) [more specifically, the standard k–ε model] approaches. A comparison of predicted model results for mean flow and turbulence with the corresponding experimental data showed that both the LES and

RANS approaches were able to predict the main characteristics of the mean flow in the array of cubes reasonably well.

Krajnovic and Davidson (2004) have demonstrated successful LES of lower Reynolds number case with no rear body slant angle, i.e. α=0º (generic bus body). Krajnovic and Davidson expect that the slanted rear end will produce a wider spectrum of turbulent scales that must be resolved in LES. In Figure 2 flow domain of the flow can be seen.

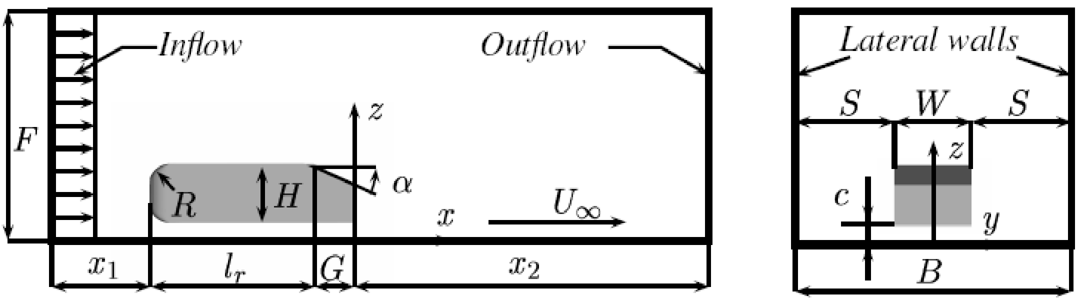

Figure 2. Schematic representation of the computational domain with vehicle body (Krajnovic and Davidson, 2004)

3. MATERIAL AND METHOD

In order to design an air rejection system utilizing the high rate of vorticity around the vehicle, determining the most proper region of the vehicle is the most challenging point. To find out this region, a numerical study is conducted. A rectangular prism is assumed as a model bus, and the flow around the model is analyzed by using the FLUENT code by employing RANS k-ε turbulence model.

In order to determine the dimensions of the flow domain, the dimensions normalized by the vehicle height H, are referenced as in Krajnovic and Davidson (2004).

By referencing the ratios of Krajnovic and Davidson, (2004), the present flow geometry dimensions and the position of the vehicle model in the channel were determined as follows;

Width of the channel (B) = 6.493xH = 6.493x 67=435 mm.
Height of the channel (F)= 4.861xH=4.861x67= 326 mm.
Distance between inflow and model front face (X_1)= 7.3xH=7.3x67=489 mm
Distance between outflow and model back face (X_2)= 21xH=21x67=1407mm
Overall length of the channel=X_1+L+ X_2= 489+ 175+1407=2071 mm.

With these results the dimensions of the computational domain and the position of the model in the domain is determined and shown in the Figures 3 and 4.

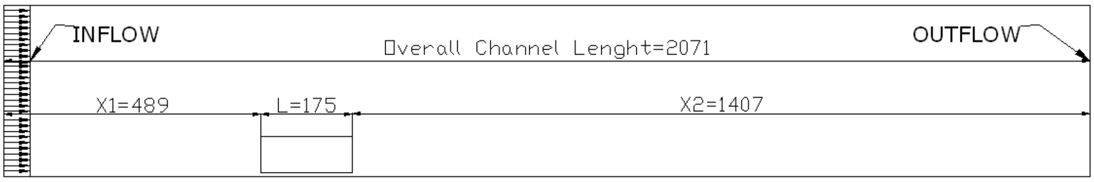

Figure 3. Position of the bus in the channel (side view, dimensions in mm)

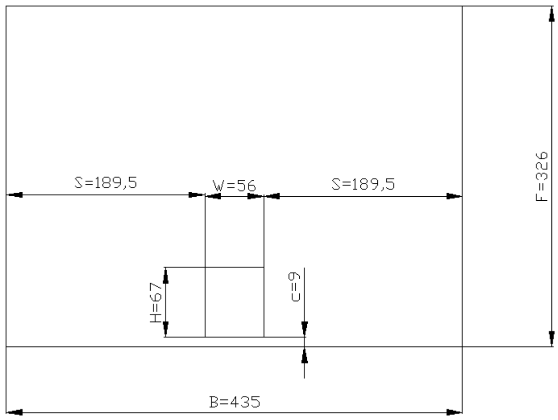

Figure 4. Position of the bus in the channel (cross-sectional view)

In the present study the 3-D finite volume, rectangular mesh is built by using GAMBIT computer code and the following boundary conditions are considered for the simulations.

1. Velocity inlet boundary conditions are used at the inflow section of the channel as approximately 90 km/h (25 m/s). The speed of the airflow was purposely taken as 25 m/s for the objective of the simulation of the real bus traveling on the road. It is assumed that only a constant and uniform stream wise-direction velocity component exists and other velocity components are assumed to be zero.

2. Free outflow boundary condition: The outflow boundary condition is used to model flow exist where the details of the flow velocity and pressure are not known prior to solution of the flow problem so that mass balance correction is applied at the outflow boundary and other data at the exit plane is extrapolated from the interior. Diffusion fluxes for all flow variables in the direction normal to the exit plane are to be zero. Therefore the outflow velocity is consistent with a close to fully developed flow assumption.

3. Wall boundary condition is used to bound fluid and solid regions of the vehicle and channel surfaces. The boundary conditions are no- slip ($u = v = w = 0$).

4. Fluid boundary condition at the fluid zone. Fluid zone is defined as group of cells for which all active equations are solved. The fluid material is set as air.

In the present study, in order to simulate the flow around the bus-shape model, a commercial package program FLUENT was employed with RANS k-ε turbulence model.

The time averaged patterns of streamlines of the flow in a horizontal plane is shown in Figure 5.

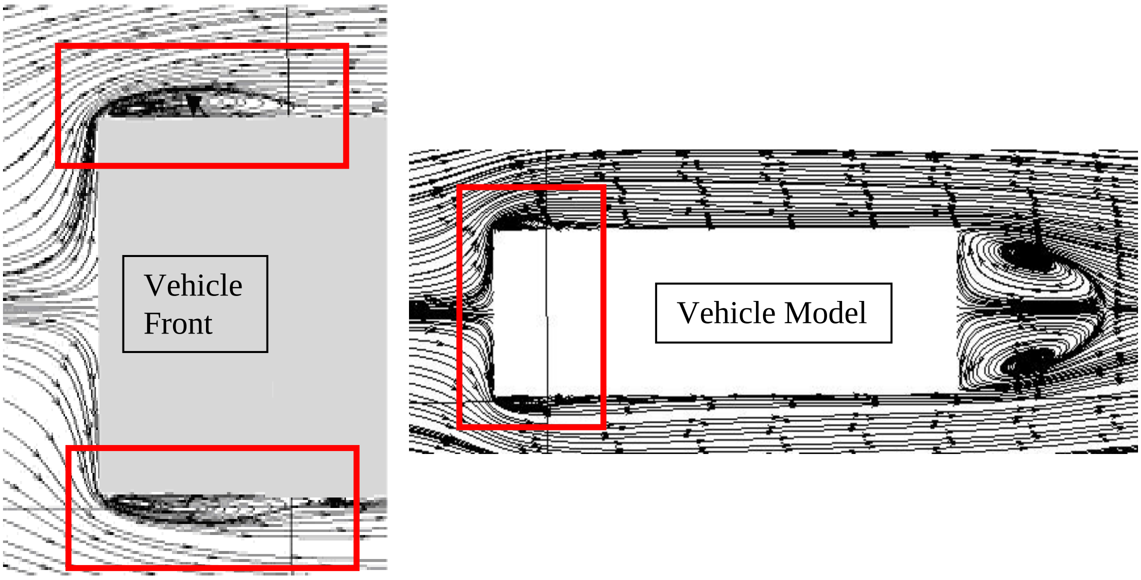

Figure 5. Time-averaged patterns of streamlines in a horizontal plane of the vehicle model

When the Figure 5 is examined, it is seen that the rate of vorticity is very high at the intersection of side, and front regions of the model bus; so this is the most proper region for the natural ventilation.

By considering the results gained from the numerical solutions and structure of the vehicle, the most proper location is determined as shown in figure 6.

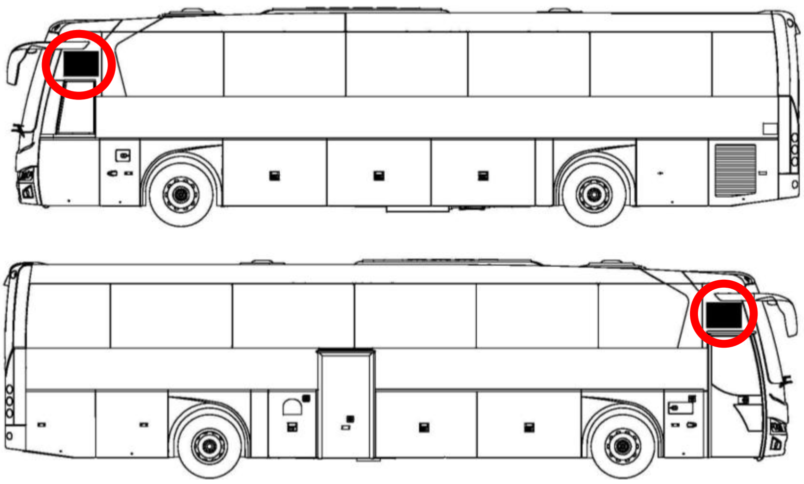

Figure 6. The regions selected for the application of ventilation

A hole having the dimensions of 268X63 mm is initiated on the right panorama glasses over the front door of a bus. An air intake box is designed to install to the inside of the glass. The shape and the dimensions of the hole created on the glass can be seen in Figure 7.

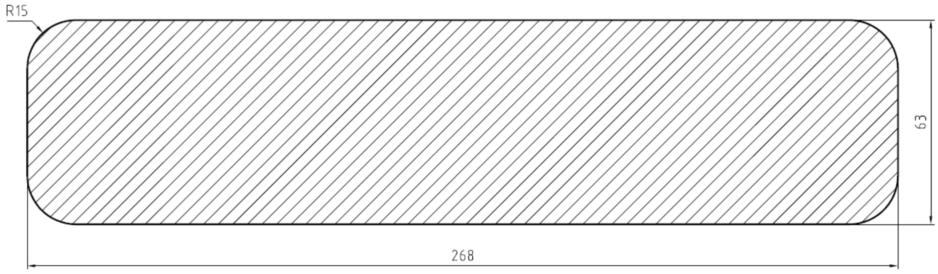

Figure 7. The shape and the dimensions of the hole on the glass

In the design process of the air intake box, the following situations are considered; in the rainy days and the times when the bus is being washed, there must be no water leakage into the bus. Also the water inside the air intake box must be naturally drained. At the end of the design process the air intake box shown in the Figure 8 is designed.

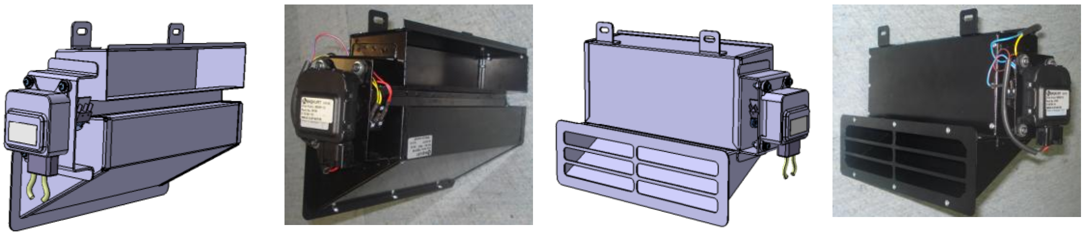

Figure 8. CAD views and real photos of air intake box

The air intake box is designed such that, the suctioning side (interior) of the air intake box has dimensions of 268X48 mm and 12.864 mm ^{2} of net area, the exhaust side (exterior) has a net area of 13.970,22 mm^{2}. Since this system is rejecting the conditioned air inside the bus to the atmosphere, opening this system all around the trip may cause some reduction on the air conditioner performance. So an electrically operated flow control flap is adapted to the inside of the air intake box. In this way, the control of the air rejection is satisfied, the control of the flap can be done by using the A/C or defroster control unit and can be connected to the fresh air intake function, or defrost function. In this study these connections are not performed, only it is focused on the determination of the amount of rejected air. The closed and open positions of the flow control flap and the section view of the air intake box are show in Figure 9.

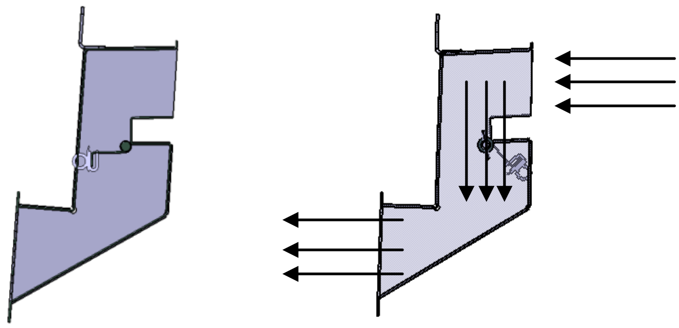

Figure 9. The closed and open positions of the flow control flap and the section view of the air intake box

In order to determine the stopping points of the flap, 2 micro switches are also installed to the system. Details of the flap system with micro switches can be seen in Figure 10.

After completing the assembly of the system members inside the bus, an air spoiler is designed and installed to the outer surface of the panorama glass, at the tip of the hole, in order to direct the air flowing through the hole. In Figure 11 the air spoiler can be seen.

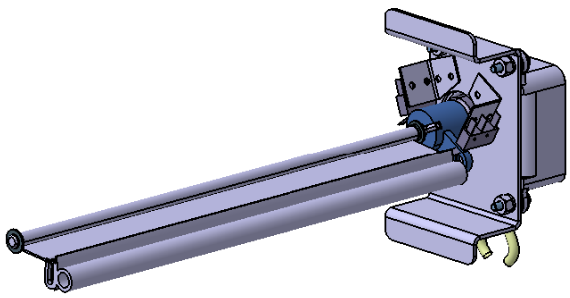

Figure 10. Flow control flap with micro switches

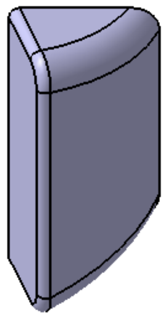

Figure 11. The air spoiler

The application photos of the designed system on the real vehicle can be seen in Figure 12.

Figure 12. The application photos of the system from the inside and outside of the vehicle

After completing the whole system assembly on the vehicle, the speed of the air flow through the suction hole is measured with different test conditions. The vehicle speed for the start of the tests is determined as 30 km/h and the speed is increased by 10 km/h, up to 100 km/h vehicle speed. In order to see the effect of air conditioner, the tests are performed with on and off positions of the air conditioner unit, and two different speeds (%50 and %100) of blower fan. In the measurements of flow velocity, a Testo 435-2 type digital flow meter is used.

4. RESULTS AND DISCUSSION

The results of the experiments performed are listed in Table 1.

Table 1. The speed of rejected air at different vehicle speed and A/C fan condition

Vehicle Speed (km/h)	Air Rejection Speed (m/s)		
	A/C off	A/C fan %50	A/C fan %100
30	2,9	3,4	4
40	3,6	4,1	4,7
50	4,3	4,8	5,4
60	5	5,5	6,1
70	5,7	6,2	6,8
80	6,5	6,9	7,5
90	7,1	7,6	8
100	7,7	8	8,5

The graphs of the suction speeds with respect to vehicle speeds in the case of A/C fan off, %50 and %100 can be seen in Figure 13.

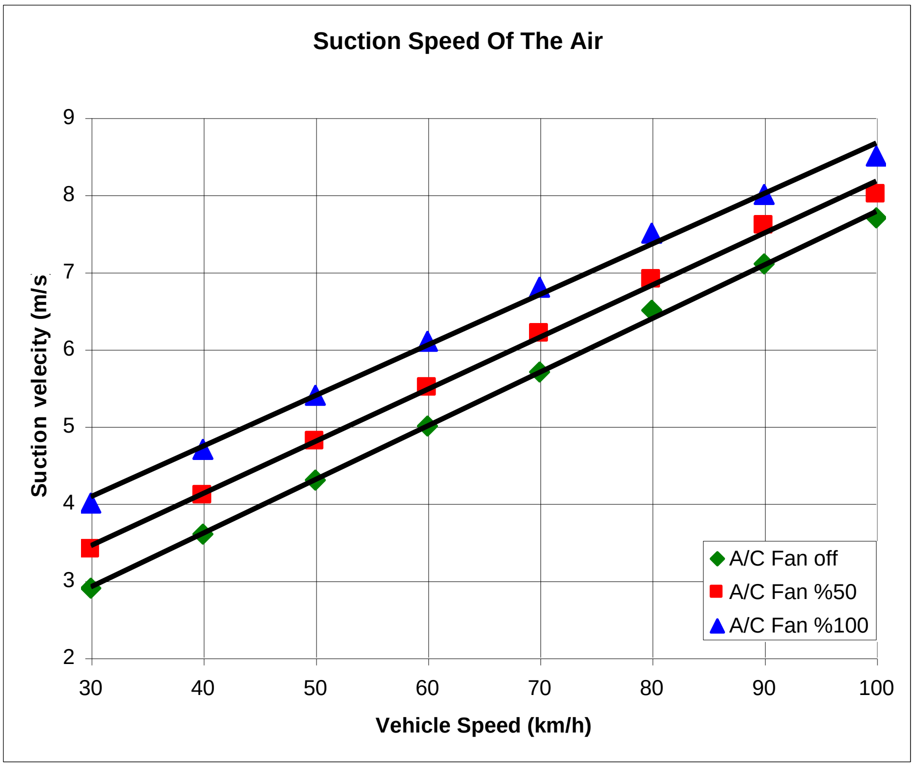

Figure 13. The graphs of the suction speeds with respect to vehicle speeds in the case of A/C fan off, %50 and %100

When the Figure 13 is examined, it is seen that the air rejection speed is directly proportional to the vehicle speed, and the relationship between them is linear. At the each of A/C fan condition, the increase in the vehicle speed creates an increase in the air rejection speed. Also when the air rejection speeds are examined under the same vehicle speed and different A/C Fan conditions, it is seen that switching on the A/C fan with %50, creates a 0,5-m/s increase in the suction speed, and, switching on the A/C fan with %100, creates a 1-m/s increase in the air rejection speed.

5. CONCLUSIONS

As a result of this study the following conclusions can be drawn;

- The air having a high value of relative humidity inside a vehicle must be better rejected to prevent fog formation and provide a comfortable media for the passengers.
- Although the impure air can be rejected by using a fan system, it can be rejected by utilizing the high rate of vorticity created by the flow around the vehicle.

- The most proper region of a bus for this application is the intersection region of the front and side of the vehicle.
- An electrical flow control flap can be controlled by the control unit of HVAC system of the vehicle. By this way an automation system can be established.
- The air rejection velocity of the air is directly proportional to the vehicle speed.
- The relationship between the air rejection velocity and vehicle speed is linear.

6. REFERENCES

1. *Urbank, T.M., Kelly, S.M., King, T.O., Archibald, C.A., Development and Application of an Integrated Dew Point and Glass Temperature Sensor, SAE 2001 World Congress Detroit, Michigan March 5-8, 2001, 2001-01-0585.*

2. *Park, W., Han, M., Jang, K., Automatic Demisting Control of Automobile Windscreen Glass, Proc. IMechE Vol. 221 Part D: J. Automobile Engineering, 2007.*

3. *A. Aroussi and A. Hassan, Vehicle Side-window Defrosting and Demisting Process, EACC 2003 1st European Automotive CFD Conference, Bingen, Germany 25-26 June 2003.*

4. *Krajnovic, S., and Davidson, L., Large-Eddy Simulation of the Flow Around a Simplified Bus. Third Afosr International Conference on DNS and LES, University of Texas at Arlington, Texas. USA, August 5-9, 2001.*

5. *Duell, E.G., George, A.R., Experimental Study of a Ground Vehicle Body Unsteady Near Wake. SAE Paper 1999-01-0812, 1999.*

6. *Cheng, Y., Lien, F.S., Yee, E., and Sinclair, R., A Comparison of Large Eddy Simulations with a Standard* $k-\varepsilon$ *Reynolds-Averaged Navier-Stokes Model for the Prediction of a Fully Developed Turbulent Flow Over a Matrix of Cubes. Journal of Wind Engineering and Industrial Aerodynamics, 91, 2003, pp. 1301-1328.*

7. *Krajnovic, S., and Davidson, L., Large-Eddy Simulation of the Flow Around Simplified Car Model. 2004 SAE World Congress, SAE Paper No.2004-01-0227, Detroit, USA, 2004.*