Bus Air Conditioning using Engine Exhaust Heat

Mukund Ranade, *Fellow ASHRAE*

Abstract

Luxury air-conditioned bus business has grown at a fast pace in recent years. The energy source for such air conditioning systems is diesel. Considering the cost of diesel per TR, the cost of the bus air conditioning is more than 2.5 times the conventional land based air conditioning. Buses are powered by the main diesel engine, which emits exhaust gases at up to 450°C. However, current technologies (like absorption or adsorption refrigeration) that use heat as the energy source for refrigeration are not suitable due to various reasons.

Jet refrigeration technology using a refrigerant has the potential to provide the solution utilizing engine waste heat. Jet refrigeration can operate on air cooled condenser, and is light and compact. This paper compares various refrigerants that can be used in such a cycle. Based on COP calculations, it is observed that a three stage jet refrigeration cycle using R245 FA refrigerant can offer optimized performance. Further, such a system can also be coupled with compression refrigeration utilizing the same refrigerant in the compressor, with common evaporator and condenser, providing air conditioning even when the bus is not moving.

Introduction

Luxury air-conditioned bus business has grown at a fast pace in recent years. The energy source for such air conditioning systems is diesel. Considering the cost of diesel, the electricity cost is about Rs.20/kW as against Rs.8/KW for other normal applications. Hence, per TR cost for bus air conditioning is around 2.5 times the conventional systems. Buses are powered by the main diesel engine, which emits up to 450°C exhaust gases. However, current technologies (like absorption or adsorption refrigeration) that use heat as the energy source for refrigeration are not suitable due to various reasons. Thus, waste heat available is currently going unutilized as a suitable technology for refrigeration or air conditioning is not available.

Jet Refrigeration Cycle

Figure 1 shows the jet refrigeration cycle.

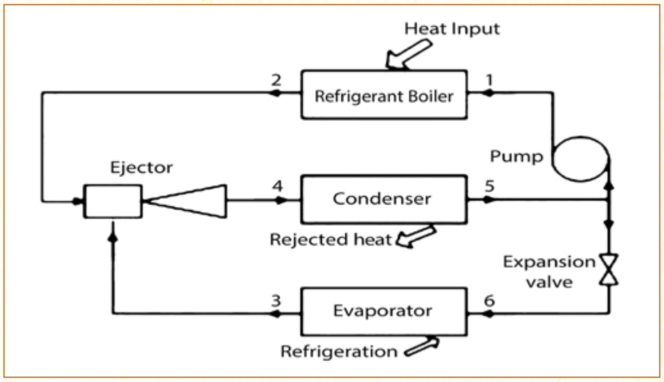

Figure 1: Jet refrigeration cycle

Heat input is given to the refrigerant boiler, which generates high pressure refrigerant vapour. The vapour is fed to a Thermo Compressor (TC) as motive fluid. TC sucks low pressure vapours from the evaporator and the mixture is delivered to the medium pressure condenser. In the condenser, refrigerant vapours are condensed by rejecting heat to the atmosphere. Condenser liquid refrigerant is now diverted in two parallel paths.

One path (5-6) goes to the evaporator through the expansion valve. After the expansion valve, refrigerant temperature drops and extracts heat from the conditioned space. Return air temperature drops and is then fed back for cooling. After extracting heat from return air, the refrigerant vaporizes and is again sucked by TC.

The other path (5-1) is fed to the refrigerant boiler by a pump for again generating high pressure vapour.

Thermo Compressor

Figure 2 shows a thermo compressor section.

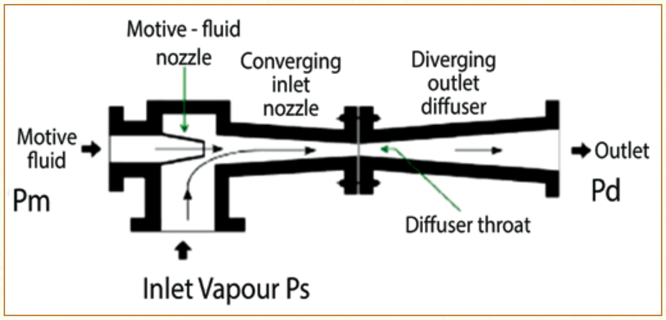

Figure 2: Section diagram of a thermo compressor

Primary flow is high pressure motive fluid at pressure *Pm*, secondary flow is low pressure suction fluid at pressure Ps and discharge flow is medium pressure mixture fluid at pressure *Pd*.

Higher ratio of Pm/Ps and lower ration of Pd/Ps will increase the output of the ejector and hence are desirable.

Choice of Refrigerant

Table 1 gives the comparison of a few refrigerants with respect to the above ratios.

Table 1: Comparison of refrigerants

Refrigerant	Nomenclature	Unit	R134A	R22	R245FA	Water	R141b
Saturation temperature	Evaporator	°C	10	10	10	10	10
Saturation pressure	Ps	Bar A	3.5	5.8	0.7	0.01	0.4
Saturation temperature	Condenser	°C	50	50	50	50	50
Saturation pressure	Pd	Bar A	13.2	19.4	3.4	0.1	1.8
Operating pressure	Pm	Bar A	40.6	49.9	36.5	10	40.5
Saturation temperature	Boiler	°C	101	96	154	180	137
Pd/Ps			3.8	3.3	5.2	14.2	5.2
Pm/Ps			11.6	8.5	55.1	1146.0	115.3
Refrigerant type			HFC	HCFC	HFC		HCFC

From *Table 1*, it is evident that the above ratios are not favorable for R134A and R22, which are the common refrigerants used for air conditioning. They are favorable for refrigerant R141b; however this refrigerant will be phased out soon, hence not desirable. Thus, two refrigerants, viz R245FA and water, appear to be suitable refrigerants.

If one uses water as the refrigerant, it will be nothing but steam jet refrigeration, which is quite a well-developed technology for land based applications. However, this technology is not suitable for bus air conditioning due its huge size and very high vacuum involved. The huge size is due to very low density. At 10°C evaporator saturation temperature, the volume of 1 kg water vapour will be more than 500 times R245FA. Similarly, vacuum will be 750 mm below atmosphere for water, which is highly leak-oriented. Generation of steam will also involve boiler regulation, which is quite difficult for a tourist bus company to handle.

Thus, R245FA seems to be the more viable refrigerant.

Figure 3 gives a good idea about the compactness of the 1 TR TC developed by Ejector Refrigeration Technology Center (ERTC), Ukraine with R245FA refrigerant. Nozzle diameters are 3-5 mm and lengths of nozzles are 25-30 mm. *Due to high density, the size is very compact.* ERTC has published performance specifications of a single stage unit. From the performance one can calculate back and derive the approximate nozzle and diffuser efficiencies they have achieved. For bus air conditioning, only air-cooled condenser option is available and the condensing temperature can be 50°C. Based on nozzle efficiencies derived, it is easy to find COP at different pressure conditions.

For single stage TC, the COP works out to 0.15, which is very low. However, three stage ejectors give COP of 0.3, which may be sufficient based on waste heat available from the bus. A 30 seater

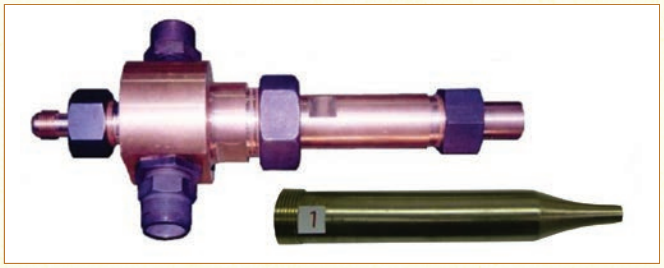

Figure 3: (Top) 1 TR TC developed by ERTC Ukraine; (bottom) nozzle of 25-30 mm length and 5 mm dia

bus has a cooling load of about 25 kW and engine capacity of 180 HP. *Table 2* shows that the energy recovered will be sufficient for cooling the bus when the engine is running at 80% load. For simplicity, exhaust heat is considered the same as engine capacity assuming 33% efficiency of the engine.

Table 2: Calculation of cooling capacity generated from bus engine exhaust

SR	Description	Unit	Value
1	Engine capacity	kW	135
2	Load on engine	%	80%
3	Engine delivered capacity	kW	108
4	Total engine exhaust heat	kW	108
5	Flue gas temperature at outlet of engine	°C	450
6	Flue gas temperature leaving exhaust heat recovery system	°C	130
7	Base temperature considered for heat recovery	°C	40
8	Approximate recoverable heat of exhaust	%	78%
9	Recoverable heat	kW	84
10	COP of three stage jet refrigeration system	-	0.3
11	Cooling available from jet refrigeration system	kW cooling	25.3

Composition of diesel can be taken as $C_{12}H_{24}$. This means carbon percentage is about 86% and hydrogen is 14%. Basic combustion calculations show that every kg of diesel consumed gives 3.1 kg of carbon dioxide. For a 7.5 TR AC system, power consumption is about 9.75 kW. The average diesel consumption per kW is 0.3 litres/kW. This means that with the density of diesel as 850kg/m^3, diesel consumption per TR works out to 2.5 kg/hr. Thus, every hour due to air conditioning load, 7.7 kg of CO_2 is released. Considering 5,000 hours of running per year, the total CO_2 emission of one bus per year works out to 38 tons of CO_2.

R245FA is available in India. Further, this refrigerant is not flammable as per ASHRAE Standard 34. Hence a compression system also can also use this refrigerant. Thus, common condenser and evaporator can be installed for jet refrigeration and compression system working on R245FA. In such a case, when the bus is not moving and the main engine is not working, air conditioning can be produced by the compression system.

Conclusion

India is a tropical country where bus air conditioning is very costly due to very high ambient temperatures. Jet refrigeration using R245FA refrigerant seems to be a very good candidate for utilizing waste heat from the bus engine and reducing carbon footprint. *The main advantage of this technology is its compact size, flexibility to locate various components at convenient locations and use of the same refrigerant for the backup compression system.*