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Determining rate of refrigerant emissions from nonprofessional automotive service through a southern California field study

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HIGHLIGHTS

- An average DIY recharging operation uses 489 g of HFC-134a.
- One-third of refrigerant is released during service or left in can heel.
- A small fraction of operations are highly emissive, responsible for most emissions.
- The results appear to be applicable to the entire U.S.

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ABSTRACT

Vehicle owners in the United States can recharge their vehicles' air conditioning systems with small containers of hydrofluorocarbon-134a (HFC-134a, CH_2FCF_3). This refrigerant, with a Global Warming Potential of 1430, may be emitted to the atmosphere during the recharging operation and from the residual heel in partially used containers, contributing to climate change. A field study was conducted in southern California to quantify the rate of refrigerant emissions from nonprofessional recharging practices and identify emission mitigation opportunities. Based on the results of the study, an average of 489 g of HFC-134a is used when recharging the sample vehicles with an average nominal charge of 858 g. An average 67% of the container content is effectively charged into the systems, 11% of the refrigerant is released during service, and the remaining 22% is left in the containers after operations are completed. A comparison with two other independent studies indicates that the findings of the current study may be applicable not only to southern California, but also to the entire U.S.

1. Introduction

Currently, most motor vehicle air conditioning (MVAC, or AC) systems in the world use 1,1,1,2-tetrafluoroethane (CH_2FCF_3, hydrofluorocarbon-134a, HFC-134a, or R-134a) as the refrigerant. HFC-134a replaced the older generation refrigerant, dichlorodifluoromethane (CCl_2F_2, chlorofluorocarbon-12, CFC-12, or R-12), identified as an ozone depleting substance (ODS) under the Montreal Protocol on Substances that Deplete the Ozone Layer (IPCC/TEAP, 2005). In the United States, the transition from CFC-12 to HFC-134a for light-duty vehicles started with the 1992 model year and completed with the 1995 model year (Atkinson, 2008). Although HFC-134a is not an ODS, it is a potent greenhouse gas (GHG) with a Global Warming Potential (GWP) of 1430 (IPCC, 2007). For this reason, its use and its emissions in the MVAC sector have been under increasing scrutiny worldwide (Taddonio, 2010).

Emissions of HFC-134a from AC systems occur under normal operating and standstill conditions ("regular" leakage) or due to accidents, stone hits, or component failures ("irregular" loss). In the U.S., vehicle owners have two options for servicing the AC system in an attempt to restore part or all of its design charge level. They can go to a professional automotive shop certified to perform AC maintenance to have the AC system serviced. Or they can choose do-it-yourself service (DIY service, or nonprofessional service) to recharge, or "top off", the system using small containers of HFC-134a (small cans). The most common small cans contain about 340 g (12 ounces) of HFC-134a. They can be purchased at auto parts stores or other retail outlets.

A vehicle owner saves money by DIY recharging an AC system with small cans compared to having a professional technician perform the recharge. A DIY recharge, however, may unintentionally release HFC-134a. This source of emission is termed release

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during service in this paper. Without a leak control device, the unused portion of the refrigerant in a small can, known as the can heel, will leak out after the charging kit is disconnected from the can, during storage, or after its disposal in a landfill.

In addition, DIY recharging operations are also associated with increased delayed emissions from system leakage compared with professional recharging operations because most do-it-yourselfers (DIYers) do not fix underlying leak problems of the AC systems.

These emissions from DIY MVAC service contribute to global climate change due to the high GWP of HFC-134a and the large number of DIY recharging operations. For this reason, these emission sources have been recognized by various legislatures and regulators in the U.S. as requiring laws and regulations. The State of Wisconsin prohibited the sale of HFC-134a in small cans, and restricted the sale and use of this refrigerant in larger containers to certified, state-registered technicians only (ATCP 136). That regulation had been in effect since 1990's as an expansion of its CFC-12 restrictions, until it was repealed by a state legislation in 2012 (Wisconsin Senate Bill 370) (SB 370, 2011). In 2007, pursuant to California's Global Warming Solutions Act of 2006 (Assembly Bill 32, or AB 32) (Núñez, 2006), the California Air Resources Board (ARB, or Board) identified the mitigation of HFC-134a emissions from DIY service of MVAC systems as one of a suite of potential measures to reduce the state's GHG emissions (ARB, 2007). A thorough understanding of the fundamentals related to these sources was called for in order to develop a technically feasible and cost-effective mitigation measure.

The results from two studies related to can heel became available in 2006 and 2007. In 2006, a small can trade group, the Automotive Refrigeration Products Institute (ARPI), commissioned Frost and Sullivan, a consulting firm, to study consumer behavior related to purchase and use of small cans to recharge their AC systems (ARPI Study). This study relied completely on a retrospective survey of the consumers who had performed DIY recharging during the 12 months prior to the survey (ARPI, 2006). The survey participants included 400 end users of small cans from California and 600 end users from other regions of the U.S. In the same year, another study was sponsored by the U.S. Environmental Protection Agency (U.S. EPA, or EPA) (EPA Study). In that study, technicians from the Universal Technical Institute (UTI) in Avondale, Arizona, conducted testing to determine the can heel after recharging was completed by different charging practices (EPA, 2007). Although informative, neither study provides information about DIY recharging behavior based on observation of recharging operations by actual DIYers, or quantification of refrigerant loss in such operations.

In order to better understand DIY recharging behavior and the associated emissions of HFC-134a, the current study was funded by the ARB and conducted by the Center for Energy and Processes (CEP) of the MINES ParisTech (École des Mines de Paris) in 2007 and 2008 (ARB Study). The study observed DIY recharging operations and measured the refrigerant released during service and lost in form of can heel. The findings were used to inform an analysis of the emissions inventory and mitigation options for emission sources, and that analysis was used by the California Air Resources Board to develop a regulation to improve DIY small can recharging practices and reduce associated emissions. That regulation became effective on January 1, 2010 (CCR, 2010). This paper presents the methods and main results from the ARB Study, and an examination of some of the findings from the EPA and ARPI Studies. The analysis of the emissions inventory and mitigation measures will be reviewed in another paper (Zhan, 2013).

2. Experimental section

2.1. Test subject profiles

During the field study to assess DIY recharging behavior and determine refrigerant loss from DIY recharging operations, the CEP team recruited a total of 50 consumers in several auto parts stores in southern California in the summers of 2007 and 2008. Thirty-six (36) of the 50 consumers had previously performed DIY recharging, or watched someone do it. In the study, 42 of the 50 consumers performed recharging operations, which were observed by the CEP team. Another 3 consumers did not perform recharging operations themselves, but rather instructed CEP staff to recharge the AC systems. The remaining 5 consumers described to CEP staff how they would recharge their vehicles. Among the 45 actual recharging operations performed during the study, 16 were done on vehicles owned by participating consumers, and the remaining 29 were conducted on 3 vehicles owned or rented by the CEP team.

The 16 consumers who provided their own vehicles for recharging came to the auto parts stores to purchase small cans to recharge their AC systems. Although the 16 DIYer-owned vehicles do not constitute a large sample set, an examination of these vehicles provides insight into the conditions under which DIY recharging takes place (Table 1).

The 16 DIYer-owned vehicles ranged from model years 1991–2004, with a mean model year of 1999 (Fig. S.1 in Supplementary Materials). Newer vehicles in their first 7–8 years of lifetime made only scant appearance. The vast majority of vehicles were 2000 and earlier model years. This age profile for DIY vehicles is qualitatively consistent with the profile of professionally serviced vehicles in another study (Atkinson, 2008).

The owners of 5 of the vehicles could not recall when their AC systems were last recharged. Another vehicle's AC system was completely empty, despite having been recharged just one day before the study, indicating the presence of irregular loss of refrigerant resulting from stone hit or component failure. The remaining 10 vehicles are considered to be valid samples for purpose of analyzing the period between recharges. Three (3) of those 10 vehicles had received AC recharging within a year, including two that had been recharged less than half a year before (Fig. S.2 in Supplementary Materials). Half of those 10 vehicles were last

Table 1
Profile of 16 DIYer-owned vehicles.

Vehicle ID	Model year	Time last recharged	Pre-service charge level	Vehicle ID	Model year	Time last recharged	Pre-service charge level
1	1999	5 months ago	43%	9	1996	long time ago	82%
2	1997	1 day ago	0%	10	2001	4 years ago	89%
3	1994	4 months ago	71%	11	1999	long time ago	81%
4	1991	N/A	6%	12	2004	N/A	72%
5	1997	10 years ago	38%	13	2004	3 years ago	87%
6	2000	N/A	61%	14	1997	1 year ago	90%
7	2003	long time ago	38%	15	2000	N/A	64%
8	1994	1994	37%	16	2002	N/A	19%