ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Evaluating the Performance of Island Kitchen Range Hoods

Iain Walker, Gabriel Rojas, Jordan Clark, and Max Sherman

September 2017

Funding was provided by the U.S. Dept. of Energy under Contract No. DE-AC02-05CH11231 and the Max Kade Foundation.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.

This paper was also published as:

Walker, I.S., Rojas, G., Clark, J. and Sherman, M.H. Evaluating the Performance of Island Kitchen Range Hoods. 2017. Proc. AIVC Conference 2017.

Acknowledgements

The authors would like to acknowledge the contributions of Woody Delp and Brett Singer of LBNL and the generous donation of range hoods for testing by Broan Nu-Tone. This work was funded by the US Department of Energy Building America Program and the Max Kade Foundation.

ABSTRACT

A key aspect of achieving acceptable indoor air quality is source control. Cooking has been recognized as a significant source of pollutants for health impacts (e.g., PM2.5 and NO_2) as well as moisture and odour. A common method of controlling this pollutant source is by using a range (or cooker) hood that vents to outside. However, field and laboratory experiments have shown highly variable performance for these devices. We use the capture efficiency metric (the fraction of the pollutants that are exhausted to outside at steady state) to characterize the range hood performance. To address this issue and provide useful information for builders, contractors, designers and home occupants, a laboratory rating method for range hood capture efficiency has recently been developed by LBNL and ASTM. The test method uses standardized emitters to create a heated plume and seed it with tracer gas. The tracer gas measurements in the room, the range hood exhaust and in the ambient air are used to estimate capture efficiency. However, this test method only applies to wall-mounted range hoods. Some range hoods are not wall-mounted: island range hoods are designed to operate over a cooktop in the middle of a room rather than against a wall and downdraft hoods draw air from near the cooktop rather than overhead. This paper discusses the development of a new test apparatus for island and downdraft hoods and presents measured capture efficiency data from example hoods. The results of this work will be used in future revisions to the ASTM standard.

KEYWORDS

Indoor Air Quality, Kitchen Ventilation, Cooking, Range Hood, Performance Standard

1 INTRODUCTION

This work builds on previous studies that developed a test method for capture efficiency of kitchen range hoods that are mounted to a wall above a cooktop. The test method has been published (or shortly will be) as an ASTM Standard (ASTM (2017)) and is likely to be adopted by reference in the near future by building codes and standards. Not all range hoods are wall mounted. Some kitchens have the cooktop in an island, rather than abutting a wall, and the range hood is mounted from the ceiling above the island. There are also downdraft devices that are mounted at the edge of the cooktop rather than above it. These island and downdraft hoods require a different experimental apparatus and testing approach due to the changes in geometry compared to the wall-mount hoods. This study investigates the development of a testing approach suitable for these hoods. So far we only have results for island applications, but the same basic apparatus and procedure will be used in future testing of downdraft hoods.

2 OUTLINE OF TEST METHOD

The test method uses the same premise as for the wall-mounted range hoods. The performance of the hood is represented by the capture efficiency (CE) that is the fraction of the plume from the cooking event that is captured by the range hood and exhausted to outside. Burners are operated on the cooktop and the thermal plume above them is tagged with a tracer gas (in our case CO_2). The steady-state concentration of tracer gas is measured in air entering the test chamber (C_i), in the test chamber (C_c) and in the exhaust air stream from the range hood blower (C_e). CE is given by:

$$CE = \frac{C_e - C_c}{C_e - C_i} \quad (1)$$

2.1 Test Apparatus

The tests are performed in a sealed test chamber (see Figure 1). The dimensions of the test chamber need to be representative of a kitchen with an island cooktop: 4.5 m by 4.6 m (with a ceiling height of 2.4 m). This is larger than the 2.3 m by 4.6 m test chamber used in previous LBNL studies developing the wall-mount hood test procedure (Kim et al (2017), Walker et al (2016), and Simone et al. (2015)). Air enters the test chamber through four 55 cm square air inlets in the corners of the ceiling. The inlets have diffuser plates and are designed to minimize the air velocities entering the test chamber because previous testing for wall-mount hoods found that this was an important factor in testing consistency (Kim et al. (2017) and Walker et al. (2016a and 1016b)). The air inlet velocities are about 0.07 m/s at 100 L/s of exhaust air flow. We expect to have a maximum exhaust air flow of about 300 L/s corresponding to an incoming air velocity of about 0.2 m/s that is substantially below the 0.5 m/s established as a minimum for the previous wall-mount experiments and stated in the ASTM standard. With these air inlets sealed, the air leakage of the test chamber was measured to be 2.5 ACH at 50 Pa. At typical operating air flows and pressures this means that less than 5% of the air entering the chamber does not come through the four inlets. All four inlets are sampled through equal length tubing and brought together in a manifold to measure C_i.

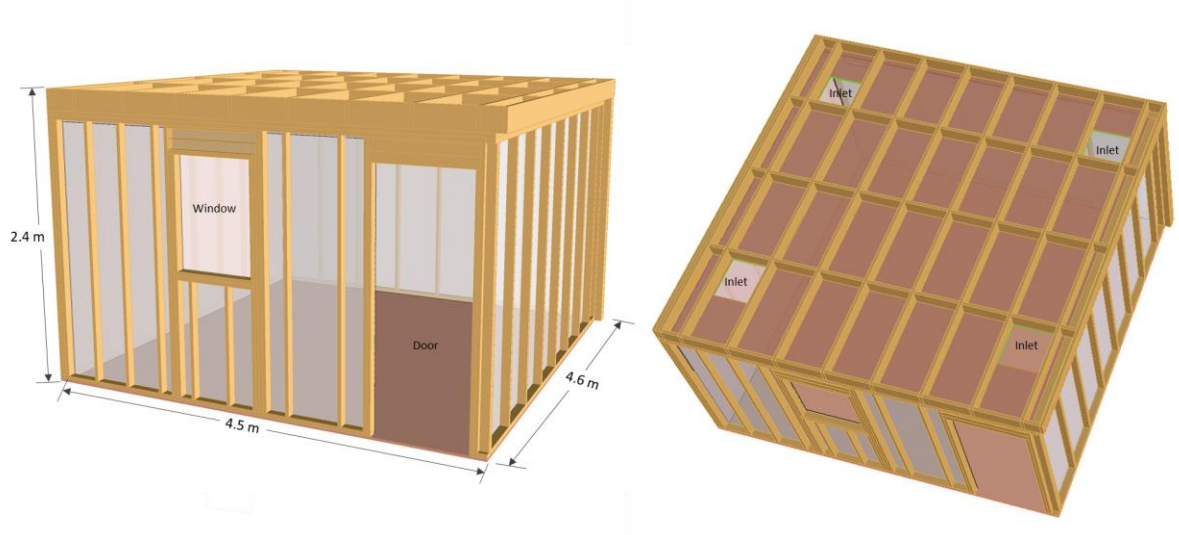

Figure 1a: Test Chamber for Island Hood Testing (Left Image: Front; Right Image: Ceiling)

Figure 1b: Island in test chamber showing cabinets, cooktops and overhead range hood

An island was built in the centre of the test chamber that has a central section containing the cooktop and sections to each side of the cooktop representing typical kitchen work surfaces. The heat sources for the plume are electric resistance cooking elements that are mounted in a custom metal enclosure. This enclosure allows us to precisely place and move the electric resistance elements in the cooktop. The power consumption of the electric elements is monitored using a Continental Control Systems WattNode WNB 3Y-208P. We attempted to meet the same power and temperature specifications as for the wall-mount testing: 1000 W and an upper plate temperature of 200°C. However, the changed air flow geometry of the island configuration meant that we could not simultaneously meet these requirements for all range hood flows. One particular problem was found for higher air flows where more than 1000 W was needed to maintain an upper plate temperature of 200°C, which resulted in unacceptably high emitter plate temperatures.

For this experiment, we investigated using lower plate temperatures and pots with boiling water (that have been used in other cooking experiments (e.g., Singer et al. (2012) and Rim et al. (2012))). These temperatures, however, are lower than cooking events that produce significant cooking contaminants and so may be too low. The following is a list of other relevant temperatures for making such a determination (note that ISO 61591 uses a temperature on 170C +/-10C):

300°C Boiling Temperature of high temperature cooking oils
230°C Smoking temperature of high temperature cooking oils
200°C Temperature for frying meat or dry frying
175°C Smoking temperature of butter and low temperature oils
160°C Temperature used for frying chicken and vegetables.
100°C Boiling water

Another problem with using boiling water is that it injects a significant amount of mass into the plume. This mass injection changes the plume dynamics and would need to be carefully controlled/specified for consistent testing. Other types of cooking events (e.g. frying eggs) inject very little mass into the plume, but produce more contaminants (other than water). So boiling water is not representative of the cooking events of interest. It may be appropriate to simulate a typical cooking event by injecting mass into the plume.

The hood to be tested was mounted on the ceiling using an adapter housing that allows the hood to be mounted at different heights above the cooktop. An inline fan and damper are mounted in the exhaust ducting from the range hood outside the test chamber. This allows us to precisely measure and control the range hood exhaust flow. C_e is measured in the exhaust ducting from the range hood outside the test chamber. C_c is measured 0.5m horizontally from the centre of the front of the range with in the test chamber at a height mid-way between the cooktop and the bottom of the range hood being tested (the same as for the wall-mount test method).

2.2 Test Procedure

The test procedure is very similar to that for wall-mount hoods. The range hood is turned on and its airflow adjusted to the appropriate level. The electric heating element is turned on and adjusted to achieve either the target power input or emitter plate surface temperature. The tracer gas injection is turned on. The heating element power input, emitter plate temperatures and the tracer gas concentrations are continuously monitored until steady-state conditions are obtained (typically after about 4 chamber air changes). During this development phase we also performed additional measurements that will not be part of a standardized test method, but are useful for troubleshooting the test approach: velocity traverses of the plume, surface temperatures of the cooktop and lower plate.

3 RESULTS

3.1 Emitter Issues

The standard emitter consists of two plates. A solid metal lower plate in contact with the heating element and an upper plate that is hollow and has many small holes for emitting tracer gas to seed the plume. The two plates are separated by three metal or ceramic standoffs allowing air to flow between the two plates. Preliminary tests in the new test chamber indicated that at 1000 W input to the heating element we could not achieve 200°C upper emitter plate temperatures that is the target in the ASTM standard for wall-mounted hood tests. We experimented with higher power input to maintain the 200°C upper emitter plate temperatures that led to over-heating of one of the emitter plates. To investigate this further we performed some experiments where we measured the temperature of the lower plate and the top surface of the cooktop and performed air velocity traverses of the plume. These tests were carried out in the wall-mount test apparatus as well as the island apparatus to see if we need to re-evaluate the existing test procedure. As well as the standard emitter we used a shallow pan (5 cm high and 22 cm diameter) and a tall pot (23 cm high and 15 cm diameter) both containing water. CO_2 was injected into the water in the pans using a spiral of perforated

copper tube. Figure 2 shows the hot wire anemometer and locations of velocity and temperature measurements.

Figure 3 shows infra-red camera images with superimposed surface temperature measurements (from surface mount thermocouples and thermistors) for a shallow pan containing boiling water and for a standard emitter plate. This illustrates that the emitter plate not only gets much hotter on its lower surfaces but also makes the whole cooktop hotter in a way that could change the air flow and plume dynamics. Figure 4 shows the vertical component of velocity profiles measured above the cooktop with three different hood air flows: off, 76 L/s and 127 L/s for the standard emitter plates, a shallow pan of water and a tall pot of water. The hood used for these tests was a microwave range hood mounted 50 cm above the cooktop. The error bars in the figures indicate the maximum and minimum of 30 measured values over a 30 second averaging time, with the mean of the measurements given by the symbol. The velocities were measured using a thermal anemometer (TA5, Airflow, UK). The velocity profiles show that the emitter plates have the plume shifted away from the centre of the emitter, towards the back of the cooktop compared to the pan of boiling water. As the hood flow increases the plume become more spread out.

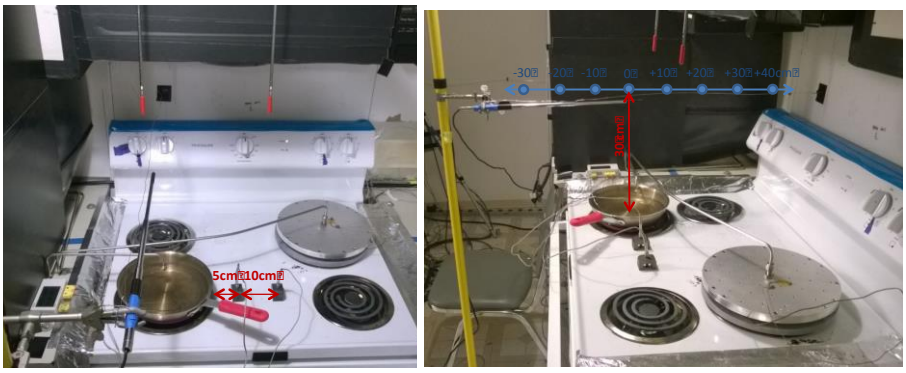

Figure 2: Illustration of velocity profile and temperature measurements

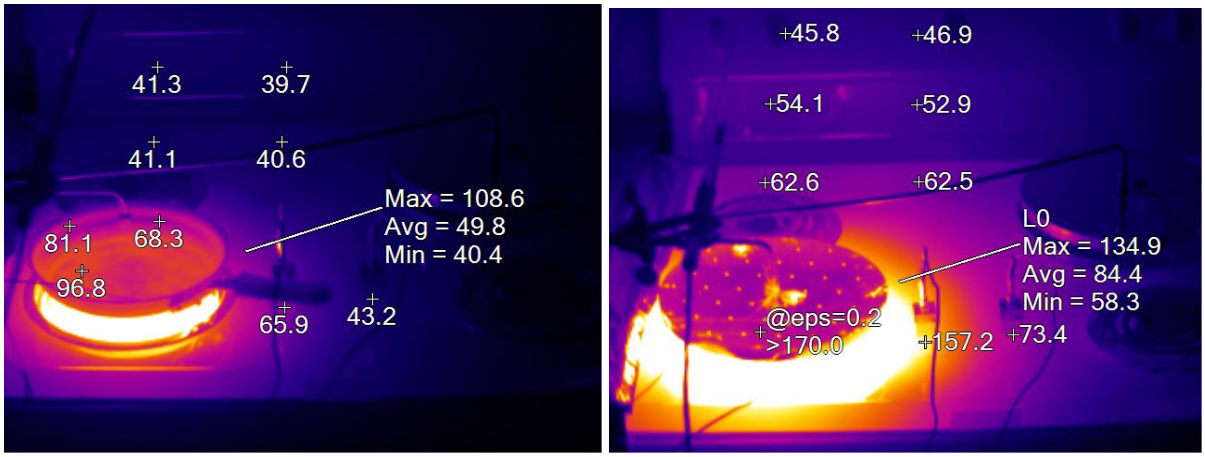

Figure 3: Pan with boiling water (left) and standard Emitter Plate (right) surface temperatures

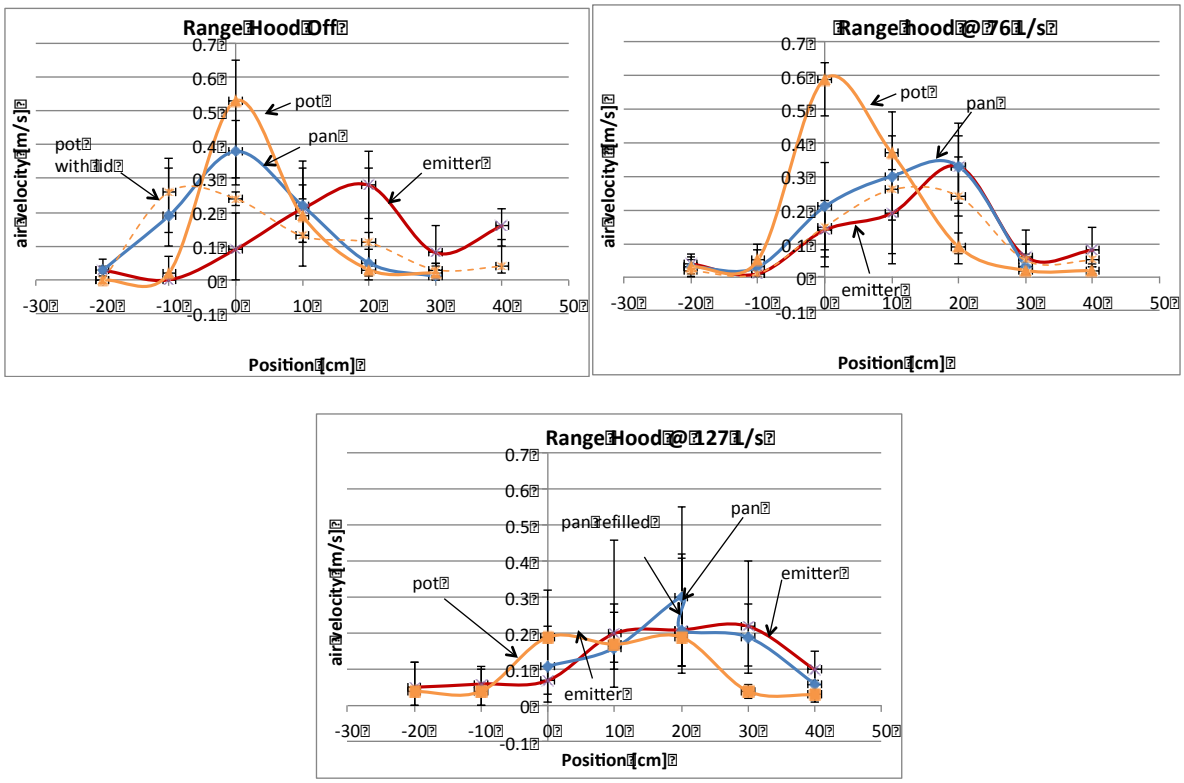

Figure 4: Plume velocity profiles for wall-mount hood – position relative to centre of heating element

For the new test chamber the velocity profiles were measured for the standard emitter plate at three different traverse heights (10, 20 and 30 cm) and the tall pot of boiling water, as shown in Figure 5. The island range hood was mounted 90 cm above the cooktop. These results reveal a complex flow pattern for the emitters. At the low traverse height we see little plume directly above the hot plate with higher velocities towards the middle of the cooktop. The plume gets closer to one from the pot at higher traverse levels as the plume develops. We also released smoke as a visual aid to get a qualitative view of the plume. This confirmed the flow patterns implies by these velocity measurements. There is clearly a flow pattern for the emitters that occurs because of the very high bottom plate temperatures and the air flow between the emitter plates. This air flow tends to be a horizontal flow from the outer edge of the cooktop towards and over the plate and as observed for both the wall-mount and island tests. The large pot filled with water did not exhibit this flow pattern.

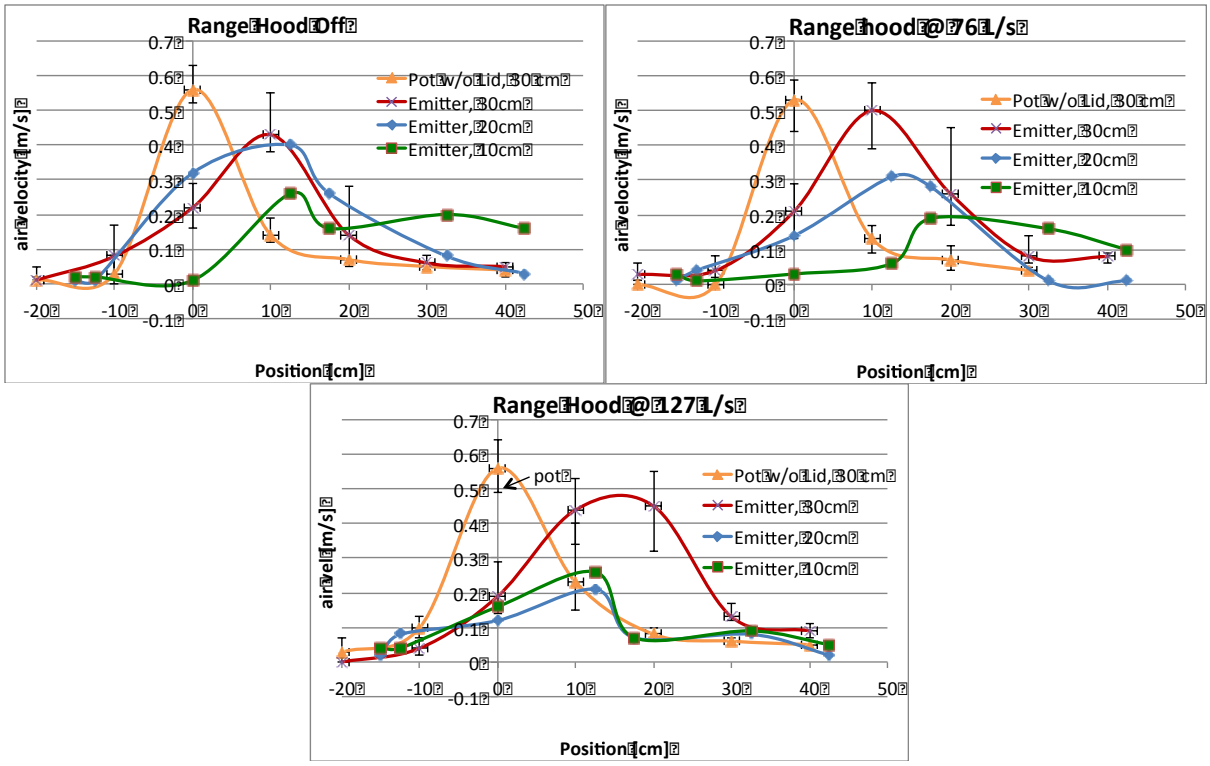

Figure 5: Plume velocity profiles for island hood at three different traverse heights– position relative to centre of heating element

3.2 Capture Efficiency for different Emitters in Wall-Mount Configuration

CE was measured in the wall-mounted configuration with a microwave range hood for the different emitters at a single hood exhaust flow of 58 L/s for a range of power inputs. We also included a couple of extra emitter types: the shallow pan dry (without water) and a shallow cast iron skillet. Table 1 summarizes measured capture efficiencies corresponding to the measured profiles in Figure 5.

Table 1: Capture Efficiency (CE) for the Wall-Mount Hood at 58 L/s

Emitter Configuration	Power Input (W)	Emitter Surface or Water Temperature (°C)	CE (%)
Pot with water	170	71	98
Pot with water	590	80	77
Pot with water	930	Data missing	68
Pan with water	170	61	95
Pan with water	640	80	75
Pan with water	940	83	65
Dry Pan, no water	920	>350	73
Skillet	940	343	82
Standard Emitter	220	87	82
Standard Emitter	650	164	79
Standard Emitter	950	199	74

Table 1 shows that the capture efficiencies decline as the power input and surface temperatures increase. The reduced energy plume is easier to capture. This trend is stronger for the water filled pot and pan than for the dry emitters, indicating that water filled emitters are more sensitive to power input. Other observations are that the boiling water containers do not necessarily have water that is uniformly at 100°C. There is also a cooling effect due to the injection of CO_2 into the water. The CO_2 is injected at low temperature due to the CO_2

cooling upon expansion from the storage cylinder to the room pressure. The single dry plate emitters (the dry pan with no water and the skillet) both have upper surface temperatures much higher than the standard emitter with its dual-plate configuration. These higher temperatures did not lead to significantly reduced CE compared to the standard emitter. This is likely because the lower plate of the standard emitter is also at high temperature and is contributing to the plume due to flow between the two emitter plates. These results indicate that a simplified single plate emitter resembling the dry pan with no water may give similar results to the standard emitter.

3.3 Capture Efficiency for different Emitters in Island Configuration

Capture efficiency was also measured for an island range hood at several flow rates with the three emitter types: dry engineered emitter, tall pot with water and shallow pan with water. Tracer gas was bubbled into the water for the pot and pan tests. All tests were conducted at approximately 1000 W. Results are shown below in Figure 6 as a function of range hood flow rate.

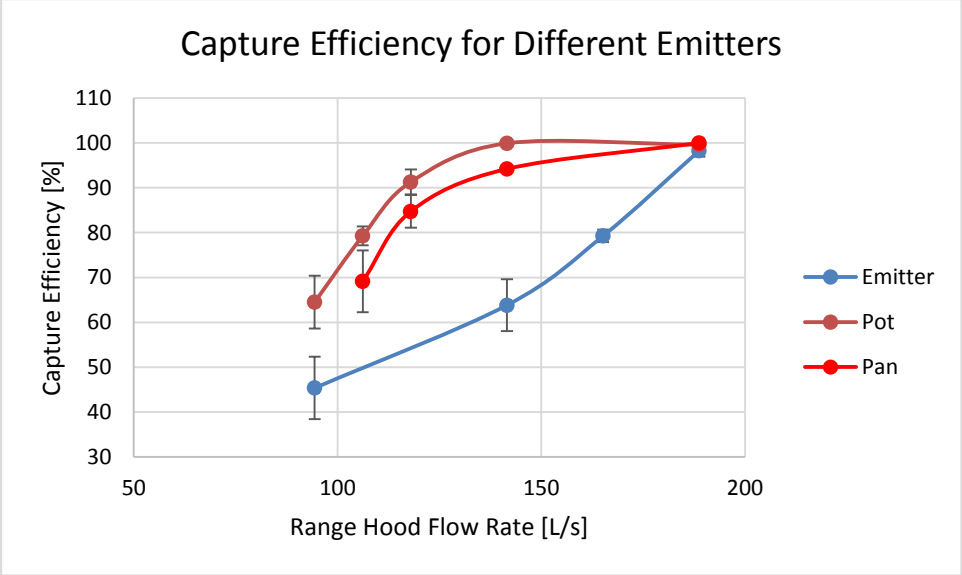

Figure 6: Capture Efficiency as a function of flow rate for different emitter types with an island range hood.

Figure 6 shows that the choice of emitter significantly affects capture efficiency. This is likely due to three differences. First, when water is included, the phase change absorbs a large amount of the energy provided by the burner, causing the air near the heating coil to be much cooler in the wet emitter cases (around 200ºC) than in the dry emitter cases (around 500ºC), and the surface temperature of the range to be cooler as well (50 ºC-100ºC with water, 100ºC-150ºC without water). Second the upward injection of mass into the plume by the boiling water creates a plume with a stronger upward momentum in the with-water cases than in the relatively diffuse plume of the dry case. Lastly, the tracer gas is relatively confined when injecting into the water in the pot or pan and all gas leaves the emitter in the portion of the plume with the greatest upward velocity. With the dry engineered emitter, a portion of the gas leaves the emitter with a horizontal velocity, thus spreading out and becoming more difficult for the hood to capture. It is not yet clear which of these cases more closely approximates the emission of combustion products from gas cooking events or ultrafine particles from hot pan or wok surfaces.

4 CONCLUSIONS

The experimental results indicate that additional work is needed in the development of a standardized test method. First, we need to determine the plume source/emitter configuration: should we be using machined emitter plates that ensure consistency but may have issues with developing plume dynamics and thermal safety, or using pots of water that might be more difficult to reproduce consistently and may result in a cooler plume that is not representative of other cooking processes. Secondly we need to determine what is a suitable operating condition for the heat source: should it be a fixed temperature plate or a fixed power input pot. Finally we will be investigating appropriate amount of mass injection into the plume.

5 REFERENCES

ASTM. (2017). Standard Test Method for Capture Efficiency of Domestic Range Hoods (Draft). American Society of Testing and Materials.

Kim, Y-S, Walker, I.S. and Delp, W.W. (2017). Development of a Standard Capture Efficiency Test Method for Residential Kitchen Ventilation. Submitted to ASHRAE Science and Technology for the Built Environment.

Rim, D., L. Wallace, S. Nabinger, and A. Persily. 2012. Reduction of Exposure to Ultrafine Particles by Kitchen Exhaust Hoods: The Effects of Exhaust Flow Rates, Particle Size, and Burner Position. *Sci. Total Environ.* 432:350–356

Simone, A., Sherman, M.H., Walker, I.S., Singer, B.C., Delp, W.W. and Stratton, J.C. (2015). Measurements of Capture Efficiency of Range Hoods in Homes. Proc. Healthy Buildings 2015.

Singer, B. C., W. W. Delp, P. N. Price , and M.G. Apte. 2012. Performance of Installed Cooking Exhaust Devices. *Indoor Air*. 22(3):223-234

Walker, I.S., Sherman, M.H, Singer, B.C. and Delp, W.W., (2016a) Development of a Tracer Gas Capture Efficiency Test Method for Residential Kitchen Ventilation. Proc. IAQ 2016.

Walker, I.S., Stratton, J.C., Delp, W.W. and Sherman, M.H. (2016b). Development of a Tracer Gas Capture Efficiency Test Method for Residential Kitchen Ventilation. LBNL-1004365.