CERP Test DC

WBS #1.2.GSA.2

Evaporative Emission Study of Specialty Systems' Solvent FC-47-G1

Core Box Cleaner Report

THIS PAGE INTENTIONALLY BLANK



Prepared by: **TECHNIKON LLC** 5301 Price Avenue ? McClellan, CA, 95652 ? (916) 929-8001 www.technikonllc.com

Core Box Cleaner Study

Evaporative Emission Study of Specialty Systems' Solvent FC-47-G1

Test # RC200098 DC

March 06. 2001

The data contained in this report were developed to assess the relative emissions profile of the product or process being evaluated. You may not obtain the same results in your facility. Data was not collected to assess casting quality, cost, or producibility



THIS PAGE INTENTIONALLY BLANK

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

Executive Summary	1
Evaporative Emission Study	3
A. Purpose	3
B. Background	3
C. Experimental Design	3
D. Experimental Setup	4
E. Results and discussion	6

List of Figures

Figure 1 - Airflow measurement
Figure 2 - Evaporation Chamber
Figure 3 - Pump pressure-flow diagram
Figure 4 - Water Net Weight vs Evaporation Time at 74°F and 0.34 scfm Air Flow Rate
Figure 5 - 70% Isopropanol Net Weight vs Evaporation Time at 74°F and 0.35 scfm Air Flow
Rate
Figure 6 - 70% Isopropanol Net Weight vs Evaporation time at 72°F and 0.6 scfm Air Flow Rate
Figure 7 - 70% Isopropanol Net Weight vs Evaporation Time at 91°F and 0.6 scfm Air Flow
Rate
Figure 8 - Acetone Net Weight vs Evaporation Time at 68°F and Still Air
Figure 9 - Acetone Net Weight vs Evaporation Time at 73°F and 0.33 scfm Air Flow Rate9
Figure 10 - Acetone Net Weight vs Evaporation Time at 75°F and 0.6 scfm Air Flow Rate9
Figure 11 - Acetone Net Weight vs Evaporation Time 74°F scfm Air Flow Rate 10
Figure 12 - FC-47-G1 Net Weight vs Evaporation Time at 74°F and 0.33 scfm Air Flow Rate-
Front End Detail
Figure 13 - FC-47-G1 Net Weight vs Evaporation Time at 74°F and 0.32 Air Flow Rate 11
Figure 14 - FC-47-G1 Net weight vs Evaporation Time at 74°F and 0.6 scfm Air Flow Rate 11
Figure 15 - FC-47-G1 Net Weight vs Evaporation Time at 74°F and 1.0 scfm Air Flow Rate 12
Figure 16 - FC-47-G1 Net Weight vs Evaporation Time at 94°F and 0.6 scfm Air Flow Rte 12
Figure 17 - Evaporation Rate vs Air Volumetric Flow Rate at 74°F
Figure 18 - Evaporation Rate vs Temperature at 0.6 scfm Air Flow Rate
Figure 19 - Relative abundance of masses in FC-47-G1 16
Figure 20 - Real Time Spectrogram of FC-47-G1 17
Figure 21 - Percent Pyrrolidone in Pyrrolidone/solvent Naphtha Vapor

List of Tables

Table 1 –	Summary of Evaporation	Rates	14
-----------	------------------------	-------	----

THIS PAGE INTENTIONALLY LEFT BLANK

Executive Summary

This report contains the results of an evaporation study conducted at the Casting Emission Reduction Program (CERP) materials laboratory of Technikon, LLC. The objective was to characterize the emissions from a three-component core machine cleaning solvent FC-47-G1, manufactured by Specialty System.

Metal casters use cores to make casting geometry that cannot be drawn from the molding cavity by simple unidirectional or rotational motion. The cores are manufactured with a refractory aggregate, usually sand, held together by one of a variety of organic or inorganic binders. The binders and sand tend to adhere to the core tooling and alter its geometry, an unacceptable situation. To mediate this situation, the process operator must stop production and manually clean the tool. The build-up of self-curing organic binders coupled with high production rates make the cleaning activity very costly, hence chemical solvent cleaners came into use. The chemical solvents dissolve the binder, reducing the labor required for mechanical removal. Further reduction in maintenance labor and increases in machine utilization are achieved when the solvent is allowed to act during non-production periods. Application of solvents during the frequent lunch and rest breaks are particularly useful because they limit the build-up of binder and shorten the time necessary for their removal.

This study followed the ASTM D3539-87 procedure used to determine the rate of evaporation for liquids. The study did not attempt to emulate the spray atomization created by the foundry application method; rather, it focused on the evaporation once in place. This approach was felt to be sufficient because it was apparent that all the liquid would evaporate; it was only a question of from where and at what rate.

The application in the foundry is conducted at approximately 90°F, but the standard for this ASTM method is 77°F. In an effort to provide the broadest base of engineering data that could be related to published data, evaporative tests were conducted near the reference temperature of 77°F as well as 92°F. Additionally, because the FC-47-G1 solvent is a three-component material, tests were conducted on common single- and two-component materials as well as the three-component solvent to aid interpretation of the evaporation data. The report contains data on acetone, water, 70% isopropyl alcohol, and the FC-47-G1 solvent.

The study reveals the following facts:

- **1.** Evaporation is characterized by two modes:
 - **a.** Evaporation from the saturated liquid surface, which is the first and fastest mode, is driven by the liquid's ability to extract heat from the surrounding environment, principally the air.
 - **b.** Once the substrate is no longer saturated, evaporation proceeds at a slower rate by diffusion to the substrate surface.
- 2. In a multi-component liquid, the components each evaporate in a linear manner,

one following the other. The order is prescribed by the liquid's vapor pressure. Where there is not a wide separation of vapor pressures the liquids co-evaporate, showing a curved transition between the two linear rates.

- **3.** The evaporation rate of the solvent FC-47-G1 is 3.3 times slower than water, 20 times slower than 70 % isopropyl alcohol, and over 80 times slower than acetone.
- **4.** The solvent FC-47-G1 will eventually evaporate completely
- **5.** Simultaneous evaporation data and real time mass spectrophotometric data demonstrated that the FC-47-G1 components co-evaporated. During the first 20 minutes the emission is estimated to be 60-80 percent pyrrolidone; the balance is heavy aromatic solvent naphtha. As evaporation continued, the pyrrolidone proportion increased. The third reported component, Ethyl-3-Ethoxypropionate, was virtually non-existent.
- 6. The FC-47-G1 solvent uniquely gained weight before the evaporation rate became dominant. This phenomenon might mislead one to conclude that there is no emission from this material. It is evident, based on simultaneous spectrophotometric and gravimetric measurements, that the evaporative emission is occurring concurrent with the weight gain. It is speculated that the weight gain is due to moisture absorption from the atmosphere until moisture saturation is achieved. The weight gain was less apparent at 92°F than it was at 75°F.

Evaporative Emission Study

A. Purpose

This study is a prototype to provide engineering data and to establish capability and protocols to do future experiments involving evaporative emission from volatile liquids.

B. Background

Solvent-based Core Box and Hopper cleaners are used extensively in the foundry industry. An evaporation characterization of a typical cleaner, FC-47-G1, was conducted to better understand the contribution these cleaners make to a foundry's VOC emissions. Typical process conditions for the use of these cleaners are shown below:

1. Core Box Cleaning: The core box is sprayed for about 45-60 seconds through a 3/8 inch pipe which sometimes has a H1/4VV-2502 spraying nozzle attached under 80-90 psi air pressure. Even without the nozzle, significant atomization occurs. The calculated spray rate was estimated to be 0.08-0.27 gal/min. The solvent is allowed to soak on the corebox for about 20 minutes, and then it is removed by the next core made, which is scrapped with the residual solvent. Approximately 10-20% of 5-6 gallons (0.5-1.2 gal.) of solvent is applied to the core box of each machine used each day. It is expected that the solvent-soaked surface varies from metallically clean to resin coated with sand inclusions.

2. Core Machine Hopper Cleaning: The hoppers are sprayed with the balance of the 5-6 gallons (4.0-5.4 gal.) using the above equipment. The adhered sand is allowed to soak for an indeterminate time, reasonably 2 to 12 hours, then the solvent-soaked sand is chipped off the hopper and disposed of along with the residual solvent. It is reasonably expected that the irregular sand surface is heavily coated with the solvent but not saturated as the solvent would distribute itself into the sand mass by gravitation and surface tension. Some solvent flows through the hopper and core machine to the floor below where it may fall on waste sand to be disposed of as solid waste. In both scenarios, all of the solvent that can evaporate will evaporate within the core room area, or from the waste sand located either within the building or in an approved waste stream.

C. Experimental Design

We are not prepared to emulate the atomization of the solvent into the air, nor the random dripping from equipment surfaces. Neither can we hope to emulate all the corebox geometries, orientations, or surface textures; however, any solvent-saturated surface would have the wet liquid solvent as the initial evaporative surface. With the assumption that we must emulate evaporation from a solvent soaked surface, we have a basis for providing engineering data from which prudent judgments can be extrapolated

Our evaporative determinations are based on ASTM method D 3539-87 (re-approved 1996) <u>Standard Test Methods for Evaporation Rates of Volatile Liquids by the Shell Thin-Film Evaporometer</u>. This method is regularly used to determine the relative evaporation rates as they appear in the MSDS data. The Shell Oil company thin film evaporometer is a specialized piece of equipment used for this test. In this method, 0.7 ml of liq-

uid is evaporated from a 90 mm diameter porous filter paper placed at right angles to the flow of dry air moving at a volumetric flow rate of 21 liters per minute down a vertical shaft. The shaft cross section is not specified so the linear velocity of the air is not known. The liquid is dispensed with a pipette, within a 2 second period, on a 60 mm diameter circle scribed on the filter paper. The air temperature is $77 +/- 2^{\circ}F$. The filter paper is suspended from a spring whose extension is used to calculate weight. When the filter is wetted with the liquid, the spring extends. The position of the filter paper is recorded every 20 seconds until the paper returns to its original dry position. The evaporation time is determined as the time necessary to evaporate 90% of the liquid weight: The longer the reported time, the slower the evaporation rate. The 90% figure is used because the evaporation rate is essentially linear in this range and avoids the slower final stages of drying. The method is reported to be repeatable and reproducible within approximately 13%.

In an effort to provide the broadest basis for estimating the emission character of this solvent, and test the sensitivity of the test process, we have provided the evaporative curves for 3 common materials, whose relative evaporation rates are published, and the solvent of interest at four air flow rates near the standard temperature and at a higher temperature. Determination of these curves also provided the necessary experience and equipment development to conduct this type of study on other materials in the future.



Figure 1 - Airflow measurement

D. Experimental Setup

Our application of method D 3539-87 replaced the spring with an analytical balance with readability of 0.1 mg. The liquid sample size was 0.7 ml and weighed 500-800 mg depending on the liquid density. The evaporation media was a Whatman 1927-9237 sixtythree (63) mm diameter porous glass filter. The liquid was placed on a 45 mm diameter circle scribed on the filter paper. The air was sourced from the air-conditioned laboratory whose temperature is regulated to $\pm 2^{\circ}$ F. When the air temperature was required to be above the laboratory ambient temperature, a heated stirring plate was inverted over the open top of the balance. The stirring plate temperature controller was adjusted to achieve the required source air temperature. The whole apparatus was allowed to stabilize before the test was begun. The filter paper was attached to a ¹/₄ inch hexhead capscrew with nuts and placed on the center of the balance weigh pan. The weigh pan was completely enclosed in a freestanding shroud that was sealed to the scale deck except for a circular opening in the center through which the filter-supporting screw projected from the weigh pan. On top of the shroud was a vertical cylindrical enclosure surrounding the horizontal filter. The top of this cylinder had a reduced inlet. A vacuum hose was attached to the weigh pan shroud so that air was drawn axially down though the vertical cylinder, diverted radially around the filter paper, and converged radially under the filter paper to exit the evaporation chamber at the base of the filter support screw between the shroud and the weigh pan (Fig 1).



Figure 2 - Evaporation Chamber

The air was passed through a pressure-snubbing tank to reduce pump pulsing, to the vacuum pump, and finally to a flow measurement device (fig 2).

The airflow was measured alternately by a positive-displacement air flow meter connected to the pump discharge, or by regulating the pressure drop across the pump and reading the pump airflow from the pump pressure-flow diagram (fig 3).



Figure 3 - Pump pressure-flow diagram

E. Results and discussion

The evaporation curves for water, 70% isopropyl alcohol, acetone, and solvent FC-47-G1, evaporated at flow rates of 0, 0.34, 0.6, and 1.0 scfm, at nominal temperatures of 75 and 90°F are shown in figures 4 thru 16.



Figure 4 - Water Net Weight vs Evaporation Time at 74°F and 0.34 scfm Air Flow Rate



Figure 5 - 70% Isopropanol Net Weight vs Evaporation Time at 74°F and 0.35 scfm Air Flow Rate



Figure 6 - 70% Isopropanol Net Weight vs Evaporation time at 72°F and 0.6 scfm Air Flow Rate



Figure 7 - 70% Isopropanol Net Weight vs Evaporation Time at 91°F and 0.6 scfm Air Flow Rate



Fig. 8. Acetone Net Weight vs Evaporation Time at 68 F and Still Air

Figure 8 - Acetone Net Weight vs Evaporation Time at 68°F and Still Air











Figure 11 - Acetone Net Weight vs Evaporation Time 74°F scfm Air Flow Rate



Figure 12 - FC-47-G1 Net Weight vs Evaporation Time at 74°F and 0.33 scfm Air Flow Rate-Front End Detail



Figure 13 - FC-47-G1 Net Weight vs Evaporation Time at 74°F and 0.32 Air Flow Rate



Figure 14 - FC-47-G1 Net weight vs Evaporation Time at 74°F and 0.6 scfm Air Flow Rate



Figure 15 - FC-47-G1 Net Weight vs Evaporation Time at 74°F and 1.0 scfm Air Flow Rate



Figure 16 - FC-47-G1 Net Weight vs Evaporation Time at 94°F and 0.6 scfm Air Flow Rte

- **2.** Evaporation of a single component liquid in a given geometric, flow, & temperature circumstance proceeds sequentially according to the following mechanisms:
 - **a.** Constant Rate Period: When there is sufficient liquid present so that the surface is virtually uninterrupted liquid, the rate of evaporation is controlled by the rate of heat transfer from the contacting air. The air must provide the heat energy to overcome the enthalpic change from liquid to vapor.
 - **b.** Second Falling Rate Period: When the liquid is insufficient to fill the surface irregularities, an additional requirement is that the liquid diffuse from the interior or subsurface to the surface to be evaporated from a surface that now has surface topography. The diffusion is rate controlling. This later case has a much slower evaporation rate and is subject to the microgeometry of the evaporation surface.
 - **c.** First Falling rate period: The transition between the constant rate period and the second falling rate period.
- **3.** Mixtures of liquids, that saturate the surface, proceed as a series of constant rate periods until the aggregate of the liquids no longer saturate the surface. The order in which the liquids evaporate depends on the relative vapor pressures of the liquids at the evaporation temperature. When the vapor pressures are similar, the second liquid begins to evaporate before the first liquid is finished creating a long transition. When the vapor pressures are significantly different, one liquid essentially evaporates completely before the next begins.
- **4.** The rates of evaporation are the slope of the various evaporative curves. These evaporative rates, when normalized to the evaporative surface area, the volumetric air flow rate, and the linear air velocity passing the annular ring between the filter media and the cylindrical shroud, are shown in Table 1. The relative evaporation rates vs. the air flow rate and temperature are shown in Figs 17 and 18. Among the liquids investigated, the evaporation rate of those liquids with higher evaporation rates appear to be more sensitive to the airflow rate. Conversely, the evaporation rate, of those liquids with lower evaporation rates, appear to be more sensitive to air temperature.

Liquid	Air Flow Scfm	Temp Deg F	Evaporation Rate at temp °F gms/sec	Evaporation Rate at temp ^o F gms/sec per sq in of surf	Evaporation Rate at temp °F gms/sec per scfm	Evaporation Rate at temp °F gms/sec per in/sec air vel @ edge
			x 10000	x 100	flow	x 100
Water	0.30	74	1.300000	3.403	4.333	4.439
70% Isopropanol	0.35	74	6.000000	15.705	17.143	17.561
70% Isopropanol	0.60	72	5.800000	15.182	9.667	9.902
70% Isopropanol	0.60	91	7.700000	20.155	12.833	13.146
Acetone	0.00	68	20.600000	53.921	N/A	N/A
Acetone	0.33	73	21.600000	56.538	65.455	67.050
Acetone	0.60	75	34.200000	89.519	57.000	58.389
Acetone	1.00	74	39.800000	104.177	39.800	40.770
Acetone	0.60	92	33.500000	87.687	55.833	57.194
FC-47-G1						
Component 1	0.33	74	0.360000	0.942	1.091	1.118
FC-47-G1						
Component 1	0.32	74	0.390000	1.021	1.219	1.248
Component 2	0.32	74	0.310000	8.114	9.688	9.924
Component 3	0.32	74	0.130000	0.340	0.406	0.416
FC-47-G1						
Component 1	0.60	74	0.300000	0.785	0.500	0.512
Component 2	0.60	74	0.260000	0.681	0.433	0.444
Component 3	0.60	74	0.130000	0.340	0.217	0.222
FC-47-G1						
Component 1	1.00	74	0.480000	1.256	0.480	0.492
Component 2	1.00	74	0.310000	0.811	0.310	0.318
Component 3	1.00	74	0.130000	0.340	0.130	0.133
FC-47-G1						
Component 1	0.60	94	0.770000	2.015	1.283	1.315
Component 2	0.60	94	0.550000	1.440	0.917	0.939
Component 3	0.60	94	0.360000	0.942	0.600	0.615

Table 1 – Summary of Evaporation Rates



Figure 17 - Evaporation Rate vs Air Volumetric Flow Rate at 74°F



Figure 18 - Evaporation Rate vs Temperature at 0.6 scfm Air Flow Rate

5. A mass spectrophotometric signature of the evaporating FC-47-G1 solvent was made using the Airsense Mass spectrometer. Fig. 19 shows the masses detected. Fig. 20 shows a real time mass spectrographic signature of the solvent evaporating in air at 94°F. Fig. 20 relates to the evaporative chart on fig.16 and shows only those masses which Fig. 19 indicated were significant. The MSDS for this solvent calls for three components: N-Methyl-2-Pyrrolidone (mass: 99), Ethyl 3-Ethoxypropionate (mass: 146), and the heavy aromatic solvent naphtha (mass: various). The evaporative charts also suggest three components. Fig. 20 however suggests that only two components N-Methyl-2-Pyrrolidone, represented by masses

98 and 99, and the solvent naphtha, represented by all the other curves except mass 146, are present in significant quantities. Note in Chart 20 masses 98 and 99 use the right scale, all others use the left scale. The representations for masses 98 and 99 are 7.5 times larger than they appear relative to all the other representations. When the spectrographic chart, Fig. 20, and evaporative chart, Fig. 16, are interpreted together, the break in the evaporative curve at 6700 seconds (112 minutes) correlates in time when the naphtha components of the spectrographic chart dip below background leaving only the pyrrolidone to continue to be a significant evaporative component. Both charts show the evaporation to be complete at 11800 seconds or 194 minutes. One additional anomaly appears in the lower temperature evaporation chart of this solvent, Fig. 12. The solvent gains weight at a decreasing rate until the evaporative weight loss overtakes the gain at about 400-600 seconds, after which the two liquids co-evaporate. The initial weight gain could result from moisture absorption from the air. Finally, the estimated percent pyrrolidone in the pyrrolidone/naptha vapor is show in Fig. 21.



Figure 19 - Relative abundance of masses in FC-47-G1



Evaporation time, seconds





Figure 21 - Percent Pyrrolidone in Pyrrolidone/solvent Naphtha Vapor