IIT Research Institute
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November 18, 1970

Mr, Otho Ulrich
Armstrong Machine Works
Three Rivers, Michigan 49093

Dear Mr. Ulrich:

Subject: Steam Humidifier Tests, Project C8197

This is a letter report describing the tests conducted and results obtained in a series of steam humidifier tests performed at IIT Research Institute. The purpose of these tests was to determine the purity and quality of air humidified by an Armstrong steam humidifier with respect to possible particle contamination from materials which might be carried over from the steam supply to the humidified air. This particle contamination could be introduced by inorganic corrosion particulates as well as condensible organic additives which might be present in the steam supplied to the humidifier.

EXPERIMENTAL FACILITY AND TECHNIQUES

An Armstrong model No. AMR32D-M steam humidifier fresh off the production line was mounted in a 618 $ft.^3$ aerosol chamber. Absolute filtered air from a HEPA filter at 1035 CFM was passed through this chamber which can be considered an expanded portion of a HVAC distribution system for the purpose of these tests. The humidifier was mounted downstream of the absolute filter using standard humidifier installation procedures as recommended in Armstrong catalogue 502B. Thus any particles produced by the humidifier could then be sampled directly from the aerosol chamber.

Two sources of steam were utilized in these tests, physical plant steam and steam from an electric boiler. The physical plant steam supply was tapped from a 100 PSIG main in the Chemistry Building with a 50 ft. run of 1 in. schedule. 80 black iron pipe. At the end of the 50 ft. run a PRV reduced the pressure to that used for the test conditions, usually in the 2 t 4 PSIG range. Following the PRV a 15 ft. run of uninsulated pipe was installed to ensure that no superheat was present in the low pressure steam

by the time it reached the humidifier. A pressure gauge, in the 5 ft. long 3/4 in. iron pipe preceding the humidifier, indicated the reduced pressure; A tap located in the 3/4 in. line permitted collection of condensate from the supply steam line. An all glass steam condenser was also used to collect steam issuing from one of the nine ports on the Armstrong steam humidifier manifold.

Although most of the tests were run with the physical plant steam supply, a Speedyelectric S-100 A2-3 steam generator could also be operated at 80 PSIG as a substitute for the physical plant steam supply. Either the physical plant or electric s'team supplies could be brought into the tee upstream of the PRV by opening the corresponding valve. The Speedyelectric generator is of the electrolyte type which requires addition of sodium bicarbonate to make the boiler water electrically conductive.

Information supplied by the IIT boiler plant engineer, Mr. Morehead, indicated that the boiler feed-water was softened with a zeolite softener. Caustic soda is then added to bring pH to the phenol and methyl orange end point. Nalco #473, an organic copolymer with phosphate and antifoam to prevent sludge deposition., is maintained between 60-80 PPM. Nalco #19, a stabilized sodium sulfite for oxygen control, is maintained between 40-70 PPM. Nalco #352, a morpholine type volatile amine, is then added to maintain the pH between 7.6 and 8.0.

Particle content of the humidified air was monitored by means of a Royco model 245 particle counter capable of sizing particles down to 0.3 μm in diameter. A Casella cascade impactor was used to obtain confirmation of the Royco particle' count in one of the tests. The short glass sampling probe which transported the aerosol from the test chamber to the, Royco particle counter had provision for electrical heating to compare the volatile and non-volatile particle count. Wet and dry bulb temperature readings before and after humidification along with knowledge of the air volume (1035 CFM) permitted a calculation of the rate of steam injection in terms of pounds of steam per minute.

RESULTS AND CONCLUSIONS

Initial tests with the freshly installed Armstrong humidifier indicated a bake-off period was required to remove condensible organics from the aluminum paint and from the pipe dope that had been used on one of the nipples in the humidifier assembly

as received. Before admitting physical plant steam to the body of the humidifier, the Royco showed less than 2 particles per cubic ft. (PPCF) 0.3 μm and larger. When the humidifier was pressurizea with steam, aerosol was observed to come off of the external painted surfaces resulting in an excessive particle count (>100,000 PPCF) even though the steam injection control valve was closed and no steam was admitted. In order to mount the humidifier directly in front of the 1000 CFM HEPA filter, the entire humidifier was placed in the chamber. In a typical installation, only the stainless steel steam manifold would be inserted in the duct, thereby avoiding the introduction of "smoke" particles from the paint bake-off of the body of the humidifier.

When the particle count had returned to below 2 PPCF followinq a 24 hour bake-off, the humidifier control valve was opened. Again the particle count exceeded 100,000 PPCF, but after an internal bake-off period of only 2 hours, the particle count had dropped to about 1000 PPCF. The particle count continued to drop, although more slowly, over a 24 hour period until counts of the order of 100-300 PPCF were observed. After several days of bake-off, tests were repeated using both physical plant steam and electrically generated steam.

In the test of 9/1 with electrically generated steam, higher particle counts, of the order of 1,100 PPCF, were obtained than in subsequent tests with physical plant steam, Table 1. The presence of impurities and added electrolyte in the electric boiler feed water (tap water with sodium bicarbonate added) . can account for these high counts, although the count may have continued to drop if the steam generator could have been operated on a continuous basis with automated feed and blow down. As it was, the electric generator could be operated only manually during working hours, limiting the test to but a few hours duration.

All subsequent tests were conducted with the physical plant steam supply so that the humidifier could be operated on a 24 hour basis to allow stabilization. Typically, counts would be high at the start of a test with the surge of steam in cold feeder lines. Therefore, the feeder lines were pressurized and steam was injected usually overnight preceding a test. Note that particle counts ranged from 23 PPCF to 295 PPCF for > 0.3 μ particles. When it is considered that normal atmospheric counts are well in the range of millions of PPCF, the very low particulate contribution by an Armstrong steam humidifier is apparent.

Table 1

PARTICLE GENERATION TESTS WITH AN ARMSTRONG MODEL AMR32D-M HUMIDIFIER

Date	Steam Supply	Before Humidification °F	Before Humidification %RH	After Humidification °F	After Humidification %RH	Steam Injection,[1] lbs/min	Particle Concentration,[2] ppcf 0.3-0.6μ	0.6-1.5μ	1.5-3.0μ	>3.0μ	Remarks
All	None-Blank					0	<2	0	0	0	
9/1	Elec.Steam	89	35	90	55	0.464.	800	250	85	0	
9/2	Physical plant steam	88	40	90	64	0.581	160	85	50	0	
9/24a	Physical plant steam	86	39	87	53	0.307		216 ppcf >0.3μ (unheated)			Test with unheated and heated sample probe
9/24b	Physical plant steam	86	39	87	53	0.307		221 ppcf >0.3μ (heated)			
9/29a	Physical plant steam	82	34	83	52	0.341		50 ppcf >0.3μ (Royco)			Comparison of Royco and Casella counts
9/29b	Physical plant steam	82	34	83	52	0.341		58 ppcf >0.3μ (Impactor)			
9/30a	Physical plant steam	77	42	81	57	0.336		23 ppcf >0.3μ			Hall air ducted to air intake for last three tests.
9/30b	Physical plant steam	76	34	81	54	0.420		31 ppcf >0.3μ			
10/23	Physical plant steam	75	43	82	58	0.407	120	40	10	0	

[1] Based on 1035 CFM of air being humidified as calculated'from humidity tables.

[2] Royco particle count unless otherwise noted: count is based on sampling rate of 1 CFM.'

If the particle count is calculated on the basis of PPCF added for each 10% RH increase at 76°F, only about 73 PPCF are added. if the highest physical plant steam particulate concentration figure is used, test 9/2. If the lowest particulate concentration figure'isused, test 9/30a, Only about 10 PPCF is added for each 10% RH increase at 76°F.

The question arose as to whether the Royco counter was counting water droplets or more permanent low volatility materials. Therefore, in tests 9/24a and 9/24b the count was compared without and with a heated sampling probe. The probe was heated to as high as 170°F, as indicated by the air temperature, but no significant difference was observed in the particle count. These results were further confirmed in tests 9/29a and 9/29b where the Royco particle counts agreed reasonably well with microscope counts taken on Casella cascade impactor samples. The conclusion is that water droplets as such did not contribute significantly to the Royco particle counts in these tests.

In the test of 10/23 condensate was collected upstream and downstream of the Armstrong humidifier as described in the beginning of this report. Approximately one quart was collected at each site, sealed in bottles, gent to the Dearborn Chemical Division of W. R. Grace and Company, and was analyzed at their laboratory in Lake Zurich, Illinois. The following test report was received, Table II.'

Table II

Dearborn Chemical Division Analysis of Condensate Samples from Test 10/23

	Upstream Concentration or Condition	Downstream Concentration or Condition
SiO_2	2.0 ppm	0.35 ppm
Ca	< 0.4	< 0.4
Mg	< 0.4	< 0.4
Na	0.23	0.04
HCO_3	5.0	7.0
CO_3	5.0	0
Cl	8.0	3.0
SO_4	< 1.0	< 1.0
NO_3	1.0	1.0
Morpholine	10.0 ppm	5.0 ppm
PH	9.2	7.9
p Alkalinity	4.0	0
m Alkalinity	12.0	6.0
Total Hardness	<1 ppm	<1 ppm
Specific Conductance	< 7 µmho	6 µmho

Note that significant reductions in silica, sodium, carbonate, chloride, morpholine and alkalinity were reported, and in particular, the morpholine content in the steam ejected from the Armstrong' humidifier was half that in condensate collected ahead of the humidifier. If steam containing-5 PPM of morpholine is used to raise the relative humidity level 40% at 76°F, one pound of steam will be used for every 133 pounds of air, or 5 PPM of morpholine in the steam will be diluted to 0.038 PPM or 38 PPB.

In conclusion, the tests conducted at IITRI indicate that once the Armstrong humidifier has passed through a bake-off period of at least 24 hours, particulate contamination by physical plant steaminjection is very low - of the order of 100 PPCF or less of > 0.3 particles for each 10% RH increase at 76°F. An electrolyte type of steam generator produced particle counts about three times as high as the IITRI physical plant steam supply. An analysis of condensate collected before -and after the Armstrong' humidifier indicated only 50% of the morpholine supplied to the unit was injected into the air being humidified. Based on a 5 PPM morpholine content in the 100% steam injected (or 10 PPM in the supply), less than 0.04 PPM of morpholine results in the humidified air when the % RH is increased 40% at 76°F.

Respectfully submitted,

IIT RESEARCH INSTITUTE

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