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DEHUMIDIFIED AIR FOR DRYING SINGLE-BASE PROPELLANT

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This project was accomplished as part of the US Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this project was to reduce the present expenditure of thermal energy during the drying of single-base propellant by using dehumidified heated air as the drying medium. Results of this study show that the use of dehumidified air for drying single-base propellant is neither cost nor energy efficient. However, the study does show that the installation of a plate type air-to-air heat exchanger between the exhaust and intake air streams will effect an annual energy savings of 679,000 kg (1,498,000 lb) of steam for a cost savings of approximately $6,400 per air dry unit/year.

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INTRODUCTION

The present method of drying solvent-type single-base propellants at Radford Army Ammunition Plant (RAAP) is to force heated air through a bed of propellant granules to remove excess moisture. The air is exhausted to the atmosphere after one pass through the propellant. This procedure is both wasteful and costly with respect to energy consumption. A laboratory study, conducted at RAAP in 1976 indicated that M1MP f/8" Howitzer propellant could be dried with unheated, dry air 22°C (72°F). However, this test required an excessive drying time to meet the propellant specification requirement. An engineering review of the problem suggested that using heated, dehumidified air with partial recycle of the exhaust air would be more cost effective than the present method of drying single-base propellants.

The current project was funded in August 1979 to authorize RAAP to continue these studies with the objective of determining the most cost effective method of drying single-base propellants. These studies included: (1) a thorough engineering review and assessment of previous work in drying single-base propellants and current technology of removing moisture from solids, with emphasis on reduction of the present expenditure of thermal energy during single-base propellant drying by using dehumidified, heated air as the drying medium, (2) the results of laboratory tests and bench-scale studies to support the engineering investigations by establishing basic data concerning the effectiveness of using dehumidified air for drying single-base propellants, and (3) a program of selected hazards analysis to assess the potential hazards in a dehumidified air propellant drying system.

ENGINEERING STUDIES

Review of Previous Work

A literature search was conducted for information concerning the use of dehumidified air for the drying of propellants (see Bibliography). Except for a preliminary laboratory test conducted at RAAP in 1976[7], no information was found on the drying of single-base propellants using this process. However, reports from Indiana Ordnance Works for Project DE-16[1] and RAAP for Projects PE-56[2] and PE-166[3] contained useful information on the drying theory and characteristic drying curves of single-base propellants.

A preliminary laboratory test conducted at RAAP in 1976[7] shows that dry, unheated air at 22°C (72°F) will dry M1MP f/8-inch Howitzer propellant to within specification limits after 74 hours of exposure as compared with a nominal drying time of 13 hours in the conventional process using heated air at 63°C (145°F) without prior dehumidification.

A review of engineering textbook theory on the drying of solids, Treybal[5] and McCabe and Smith[9] shows that the drying process may proceed in one or two stages, depending on the initial moisture content of the solid. The first stage of drying (constant rate) is the evaporation of surface moisture from the solid. This, as the name implies, occurs at a constant rate of moisture removal per unit of time. The second stage of drying (falling rate) is the removal of moisture from within the solid. The rate of evaporation is dependent on the rate of diffusion of the moisture from the interior of the solid to the surface. Therefore, the falling rate period of moisture removal from the solid begins at the point where all of the surface moisture has been evaporated (critical point) and the final drying is accomplished at decreasing rates of moisture removal per unit of time (figure 1). Both types of drying rate are exhibited in the DE-16 and PE-56 project reports.

Current Plant Operations

A review was made of current plant operations in the Open Tank Air Dry area. Typical cycles for maximum production rates of various single-base propellants are shown in table 1. This study was based on M6MP propellant in lieu of M1MP since the M6 was the major production item at the time. The drying cycles of the two propellants are very similar--12 hours on temperature for M6 as compared to 13 hours for M1. Energy and economic calculations presented herein (Appendix B) are based on M6MP for 155-mm gun; however, these values should be readily translated to other single-base propellant drying operations.

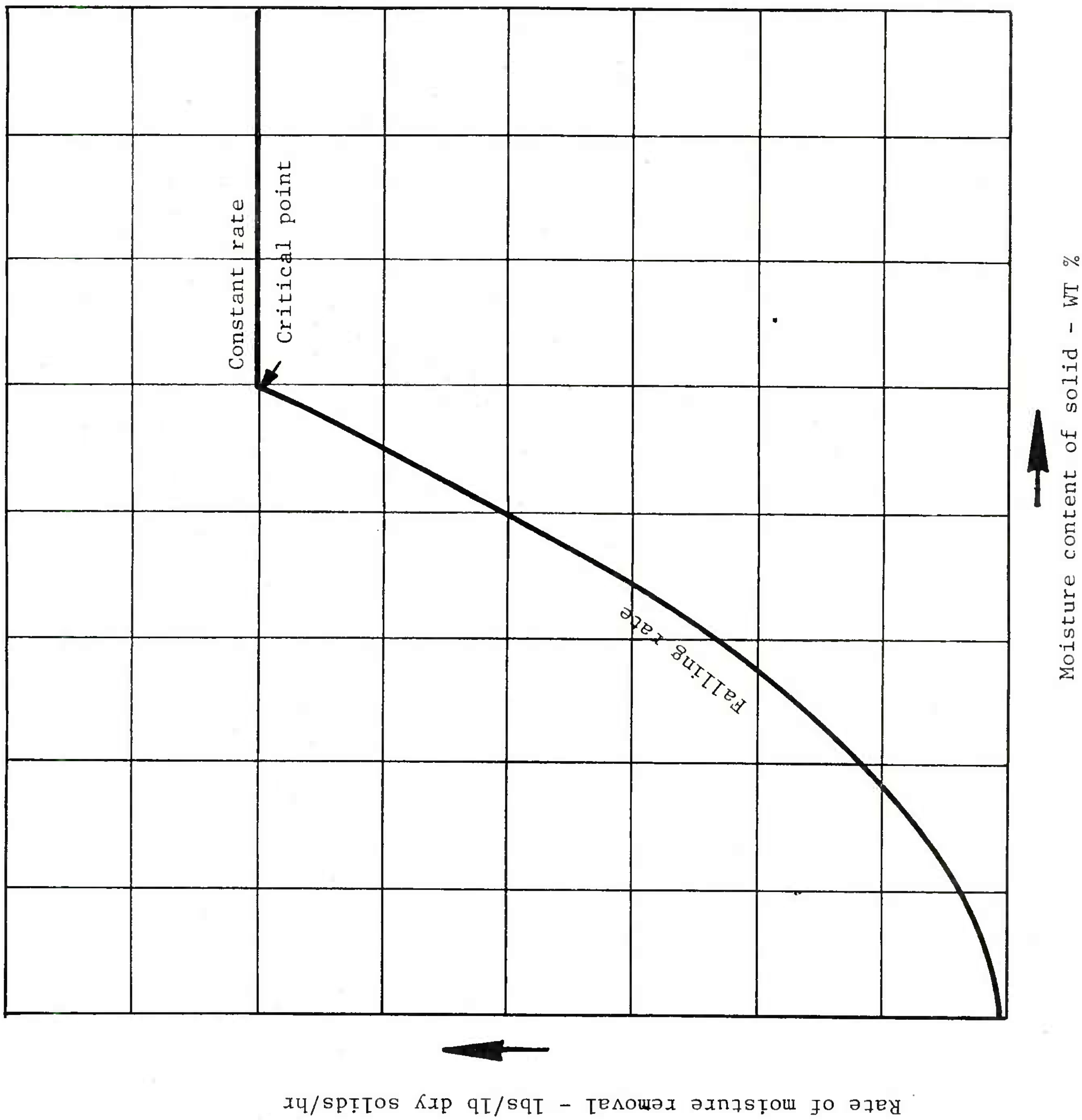


Figure 1. Typical drying rate curve for a solid material

Table 1. Open tank air drying of single-base propellants

Propellant	BS-NACO	M1MP	M6MP
Charge weight, lbs (dry)/tank	5200	5200	5200
Charge weight, kg (dry)/tank	2358.7	2358.7	2358.7
Total monthly production, lbs	2×10^6	1.375×10^6	1.7×10^6
Total monthly production*, kg	907,200	623,700	771,120
Drying cycle, hrs			
Charge tank	1.0	1.0	1.0
Heat and air on	15.0	13.0	12.0
Cool down to 37.8°C/100°F	1.0	1.0	1.0
Pull charge from tank	0.5	1.0	1.0
Total cycle	17.5	16.0	15.0

*Based on historical averages at RAAP.

Air flow measurements were taken on several air dry tanks during the drying cycle to check the validity of the fan rating of 2596 l/sec (5500 SCFM). The test values ranged from 2515 to 2579 l/sec (5328 to 5464 SCFM), which is well within experimental accuracy for the Pitot tube and Dwyer manometer used for the measurements. This data was used to establish an air flow of approximately 0.47 l/sec (1.0 SCFM) per pound of wet propellant charged for bench-scale testing. The fan rating of 2596 l/sec (5500 SCFM) is used throughout the calculations for economy and energy consumption.

Temperature records of the air exiting the blower being fed directly to the drying tank show an almost instant increase to the desired setting of 63°C (145°F) when the blower and temperature controller are activated. These records also show very little fluctuation around the temperature control set point during the drying cycle.

During the study, PE-432[8], conducted from June through August of 1979, M6MP f/155-mm propellant air dry cycles were monitored with steam to propellant ratios of 1.1 to 1.5 kg steam per kg propellant (lb/lb) being found. The highest steam consumption occurred in June and the lowest in August as would be expected from the higher ambient air temperature in the latter month (see Appendix A4).

Temperature and relative humidity recorded inside an open tank air dry bay show that the cycles varied from 12 to 17 hours (average of 15 hours) for energy consumption which is up to 5 hours longer than the standard heating period. The recorder charts also show that the relative humidity within the bay immediately rose to 96 percent and remained for approximately one hour after which it sharply decreased to 30 percent over the next three hours and gradually drifted down to 27 percent during the remainder of the cycle. The bay temperature did not record [38°C (100°F) minimum on chart] for the first hour of the cycle, then steadily increased to 58°C (136°F) over the next four hours. The bay temperature then showed a gradual increase to 60°C (140°F) over the remainder of the heating cycle. No ambient air relative humidity or temperature records are available for the dates of these studies; however, the extended cycle would indicate some adverse condition in drying and this was assumed to have been high relative humidity in the ambient air.

Calculations (Appendix A) were performed around the air delivery system for the open tank air dryers to establish theoretical energy consumption values for various atmospheric conditions of temperature and relative humidity and for normal and extended drying cycles. Since the altitude at RAAP has some effect on the relationship between percent relative humidity and specific humidity, as opposed to conditions at sea level, psychometric data were calculated for this altitude and used in these calculations.

These data show no effect on steam consumption for a given drying cycle and average ambient air temperature over the range of 0 to 100 percent relative humidity, but do show an increase for an extended drying cycle at the same condition. This calculated to an added steam cost for M6MP propellant of $29,964 per year at maximum production rate at the cooler ambient air temperature, with the drying cycle extended 3 hours beyond normal. Since the energy consumption is a function of ambient temperature and cycle time, it was hoped that the bench-scale studies would show a significant reduction in cycle time by dehumidification of the drying air.

Bench-Scale Propellant Dryer

Equipment Selection

The original concept of this project (figure 2) included the modification of an existing pilot-scale drying unit previously used in the development of design criteria for the Continuous Automated Single-Base Line (CASBL) propellant manufacturing facility to include the features of air dehumidification, air recycle, and waste heat recovery. However, review of the building's condition, in which the equipment was located, determined that excessive repairs would be required and that it could not be accomplished with the project funds available.

The bench-scale dryer used in studies for development of design criteria for the Continuous Automated Multibase Line (CAMBL) propellant manufacturing facility was found to be available, in operating condition, and therefore it was selected for use in this project. Although this unit could be modified for propellant drying studies using various levels of humidity and temperature, the equipment size and design precluded the inclusion of a small regenerative air dehumidifier, waste heat recovery unit, and partial recycle of the drying air. However, it was decided that enough data could be generated from this unit to determine the overall effect of humidity and temperature of the drying air on the M6MP propellant drying cycle.

A sketch of the modified system is shown in figure 3.

Equipment Description and Modification

The original bench-scale drying system consisted of an air heater, water heater, hot water circulation pump, and air drying chamber. Plant air was reduced from 894.5 to 239.3 kPa (115 to 20 psig) for instrument control and further reduced through a flow control valve to a few centimeters (inches) water column pressure (WC). This forced the air through the air heater, down through the propellant in the drying chamber, through a gas-liquid scrubbing column, and then vented to the atmosphere.

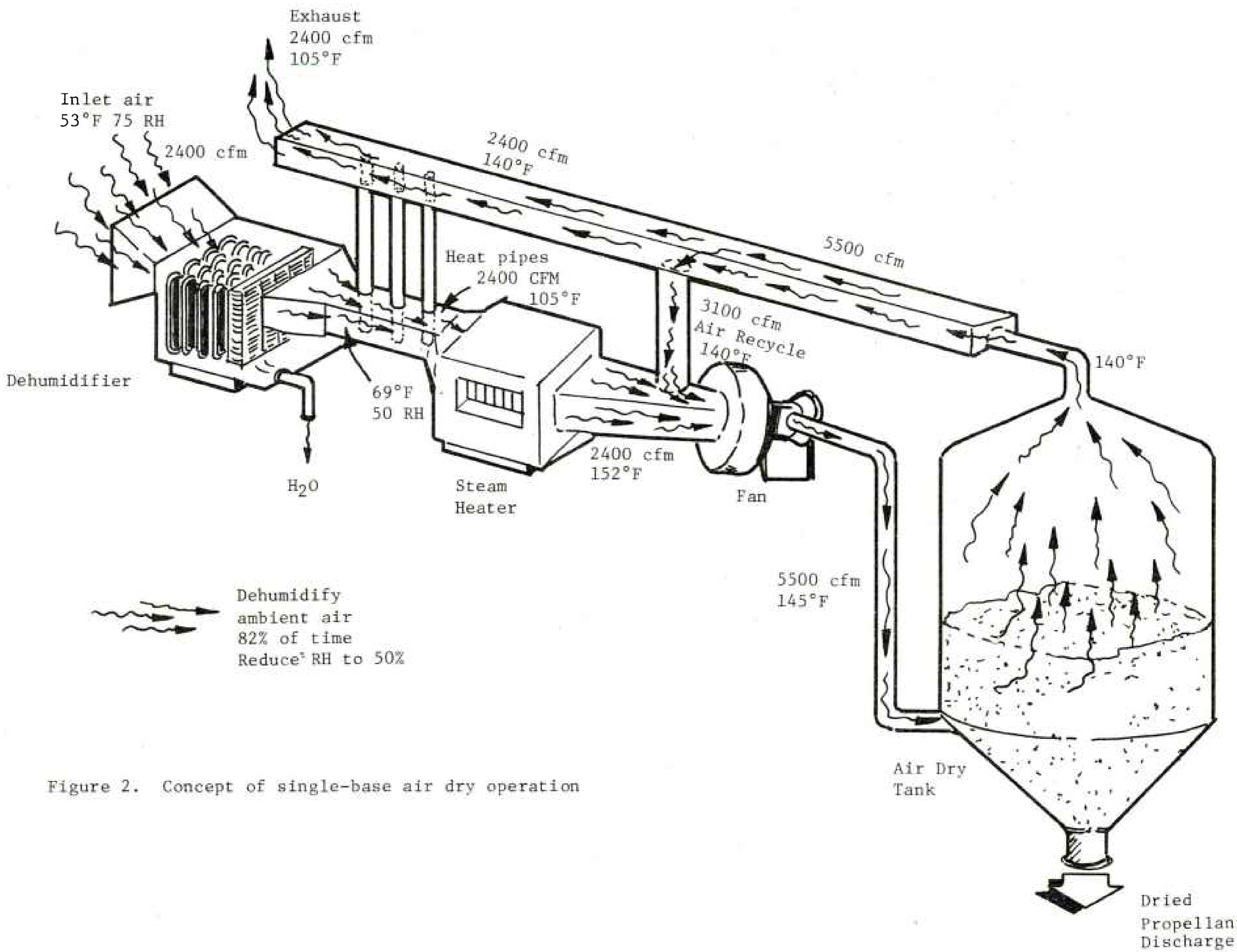


Figure 2. Concept of single-base air dry operation

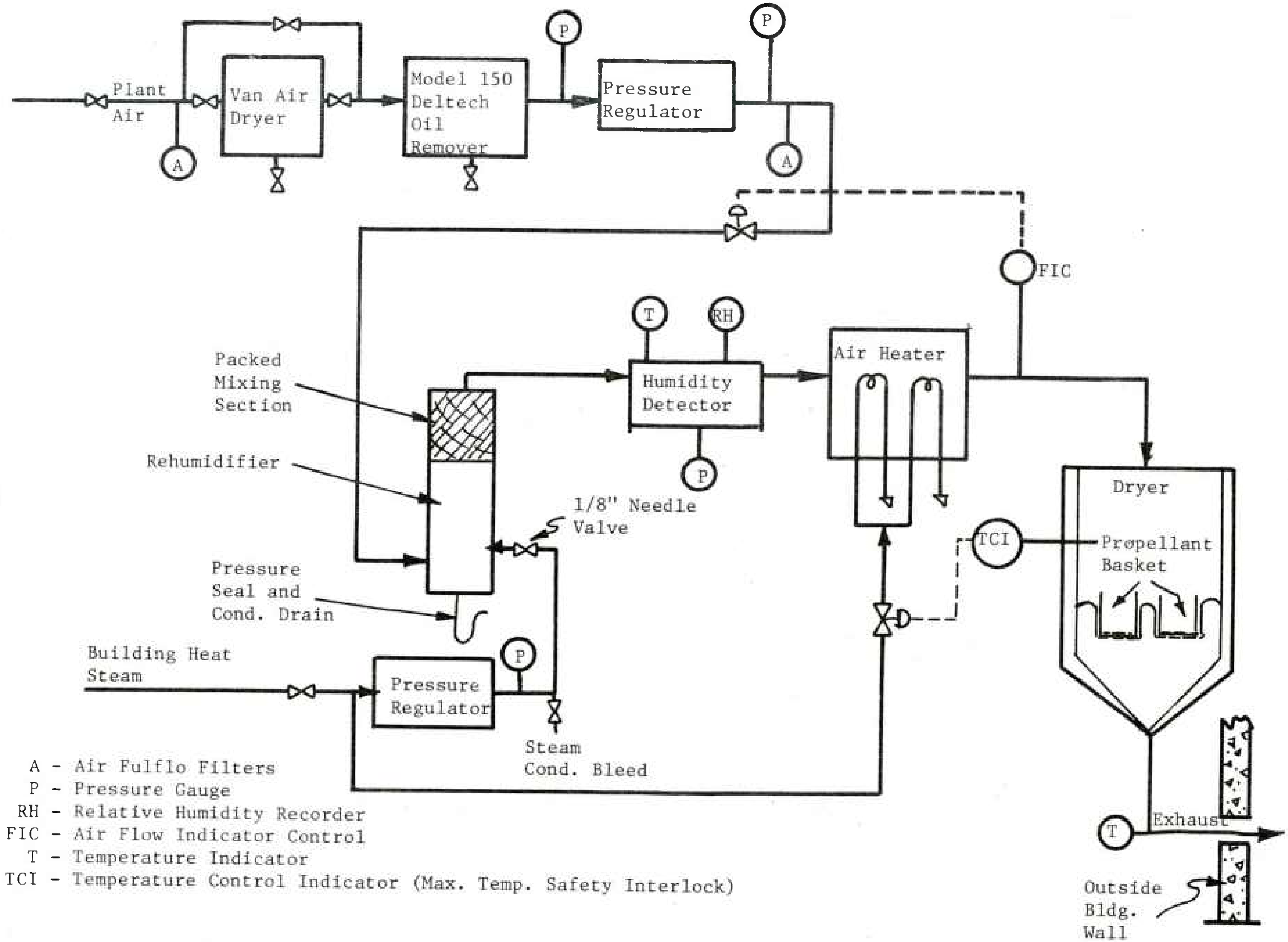


Figure 3. Single-base propellant bench-scale dryer process flow sheet

The modified drying system (figure 3) used the drying chamber, air heater, and pertinent temperature and flow controls from the original equipment. The hot water circulating system and gas-liquid scrubber were not used. In addition, a desiccant-type air dehumidifier and oil remover were installed in the plant air supply lines. A steam injection rehumidification section and relative humidity sensor were installed ahead of the air heating coils; otherwise, operation of the unit was the same as the original concept.

Air Dryer and Oil Remover

In order to provide clean, dry air from the plant air supply for adjusted humidification in the bench-scale system, a Van Air Dryer (Model D6) and a Deltech (Model 150) compressed air filter were installed in the plant air supply line 894.5 kPa (115 psig). These units were preceded and followed by Fulflo filters (Model AF 34) for initial knockdown of entrained moisture and oil droplets and final polishing of the air.

The Van Air Dryer was packed with approximately 15 kg (33 lbs) of Van Air Dry-O-Lite desiccant pellets and designed for a maximum air flow of 12.3 l/sec (26 SCFM) at a pressure of 894.5 kPa (115 psig). The desiccant is a nonregenerative, proprietary formulation of Van Air Systems, Incorporated. As the desiccant absorbs moisture from the air, the pellets slowly dissolve and the resultant solution must be periodically drained from the unit. The desiccant is a nontoxic, inorganic material which presents no flammable or explosive hazard and contains no hazardous ingredients. The drain solution is also nontoxic and presents no environmental hazard. The material meets both OSHA and USDA standards for use. Testing in the bench-scale system indicated an essentially bone-dry air product from the Van Air Dryer.

The Deltech oil filter is designed to operate at an efficiency in excess of 99.99 percent removal of 0.5 micron particle size of lubricating oil and other contaminants. Air entering the filter undergoes a directional change which causes the larger particles to impinge on the housing. As the air moves downward through the housing, coarse brushes remove rust, scale, dirt and large droplets. The air stream then enters a disposable cartridge where it passes through a random mesh of metallic strands used as a coarse coalescing element and finally passes through a bed of a Deltech Engineering, Incorporated proprietary adsorbent (organic polymeric resin) for polishing. The resin is visible through the Lexan (extruded polycarbonate) housing of the disposable cartridge and indicates exhaustion of the filter by a sharp color change of the resin. The resin is a nontoxic, nonhazardous material which has been approved by OSHA for use in Class D compressed air systems for breathing apparatus. Rated capacity of the Deltech oil filter at 894.5 kPa (115 psig) is 100.7 l/sec (213 SCFM).

The Van Air Dryer and the Deltech oil filter have far greater rated capacity than the flow required for the bench-scale dryer and were available on plant from other projects; thereby, reducing the equipment procurement costs to this project.

Rehumidifier

In order to provide controlled relative humidity in the drying air supply to the air heater, a rehumidification section was fabricated at RAAP and installed in the bench-scale system (figure 4). Clean, dry air from the Van Air/Deltech filter system was reduced to 239.3 kPa (20 psig) and further reduced through the air flow control valve to essentially atmospheric pressure before entering the vertically mounted rehumidification chamber through a 5.1 cm (2-inch) pipe welded into the chamber side 27.9 cm (11 inches) from the bottom. The chamber consists of a 68.6 cm (27 inches) section of 7.6 cm (3-inch) stainless steel pipe with the air nozzle, a 0.6 cm (1/4-inch) steam inlet located 22.8 cm (9 inches) above the air inlet and a 1.3 cm (1/2-inch) bleed valve on the bottom to drain any accumulation of steam condensate from the system. The original design included a 0.64 cm (1/4-inch) copper ring with 0.1 cm (1/32-inch) holes on 1.3 cm (1/2-inch) centers to be inserted into the chamber for even steam distribution into the air. However, the distribution ring required an excessive steam flow to prevent condensation and adequate relative humidity control at levels below 75 percent could not be obtained.

In order to obtain the desired relative humidity control, the distributor ring was removed from the chamber and a 0.64 cm (1/4-inch) Hoke needle valve was installed to inject steam into the air stream. Further control was obtained by installing a 1.3 cm (1/2-inch) Leslie pressure reducer in the steam supply header to maintain the steam pressure at selected levels between 108.27 and 134.86 kPa (1-5 psig). A 1.27 cm (1/2-inch) globe valve was installed on the end of the steam supply header to provide a constant bleed and preclude any condensate accumulation in the header.

Between the rehumidification chamber and the relative humidity sensor, a 30.5 cm (12 inches) long, packed section of 7.6 cm (3-inch) pipe was installed to assure thorough mixing of the air and steam. The packed section consisted of a rolled pad of Kynar Mist Eliminator (Type 2615) material inserted into the 7.6 cm (3-inch) pipe section. Perforated aluminum plates with 0.31 cm (1/8-inch) diameter holes on 0.953 cm (3/8-inch) centers and patterned on 1.3 cm (1/2-inch), 2.22 cm (7/8-inch), and 2.86 cm (1-1/8 inches) radius circles were mounted between the connecting pipe flanges at each end of the packed section to hold the packing in place.

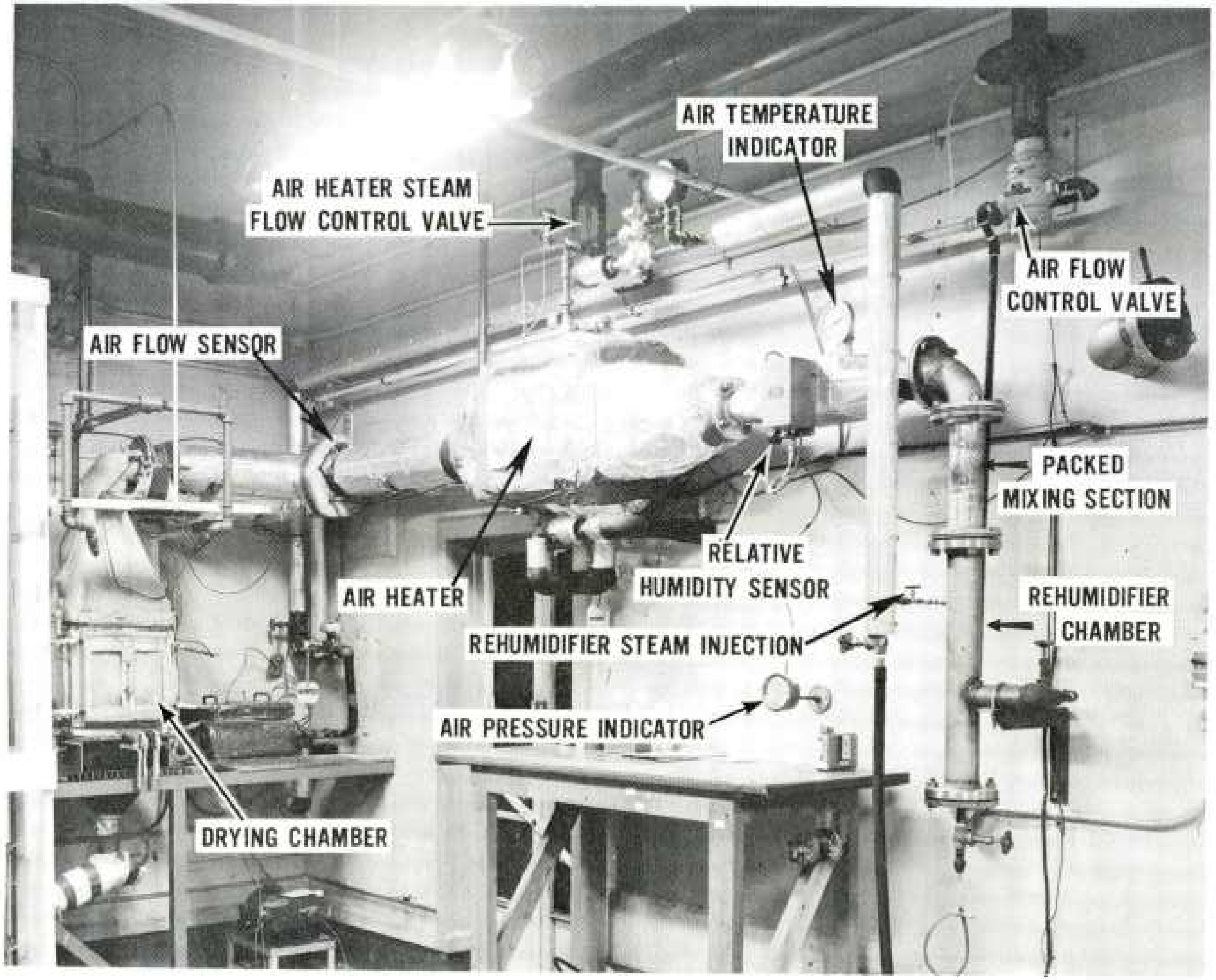


Figure 4. Single-base propellant bench-scale dryer

Relative Humidity Sensor

A Taylor Relative Humidity Transmitter (Model 207T, Type Z112) was installed between the packed mixing section and the air heater. The duct work to house the transmitter consisted of a transition section 25.4 cm (10 inches) long from the 7.6 cm (3-inch) pipe to 15.2 cm by 20.3 cm (6 inches by 8 inches) rectangular duct on each end of the 20.3 cm (8 inches) housing.

The relative humidity transmitter operates on a motion balance principle, using humidity sensitive nylon strands to create motion and a change in an air nozzle gap, which in turn transmits a 122.1 - 204.8 kPa (3 - 15 psig) signal to a Foxboro recorder (Model 5310E). The instrument was obtained from another project at RAAP and recalibrated prior to installation; thus saving on equipment procurement costs for this project.

Accuracy of the instrument is specified as $\pm$ 4 percent between 30 and 80 percent relative humidity. The calibration range was 0 to 100 percent relative humidity. Ambient air temperature operating limits of 10°C to 37.8°C (50°F to 100°F) were maintained during evaluation runs to assure the accuracy.

Air Heater

The air heater consists of three banks of steam coils located in a rectangular plenum of 0.1 m^3 (2.05 ft^3) with an inlet transition from the 7.6 cm (3-inch) flange of the relative humidity sensing chamber and an outlet transition to the 10.2 cm (4-inch) heated air duct to the drying chamber (figure 4). The steam supply to the coils was maintained at 135.86 to 149.66 kPa (5-7 psig), reduced from the 446.21 kPa (50 psig) plant steam header, and controlled through a 1.3 cm (1/2-inch) Foxboro (Model F8) pneumatic valve. Air temperature was controlled from a thermocouple located in the upper portion of the drying chamber. An ACROMAG transmitter (Model S-315-BX-U) converted the thermocouple signal to a 4 - 20 milliamp (ma) signal for input to a Fisher Electronic Indicating Controller (Model TL-101). The controller outputs a 4 - 20 ma signal to a Fisher Electro-Pneumatic transducer (Type 546) that converts the signal to a 122.97 - 204.83 kPa (3 - 15 psig) air supply to operate the Foxboro steam supply valve to the air heater. Wide fluctuations in air temperature necessitated modifying the system by blanking off one bank of the steam coils, manually throttling a second bank of coils, and installing a 0.6 cm (1/4-inch) tube between the control valve and the coils to limit the valve steam flow capacity. These modifications to the system enabled the attainment of a consistent air temperature control of $\pm$ 1.7°C ($\pm$ 3°F).

Dryer

The drying chamber (figure 5) is of aluminum construction with hot water panels in the walls. The interior of the chamber consists

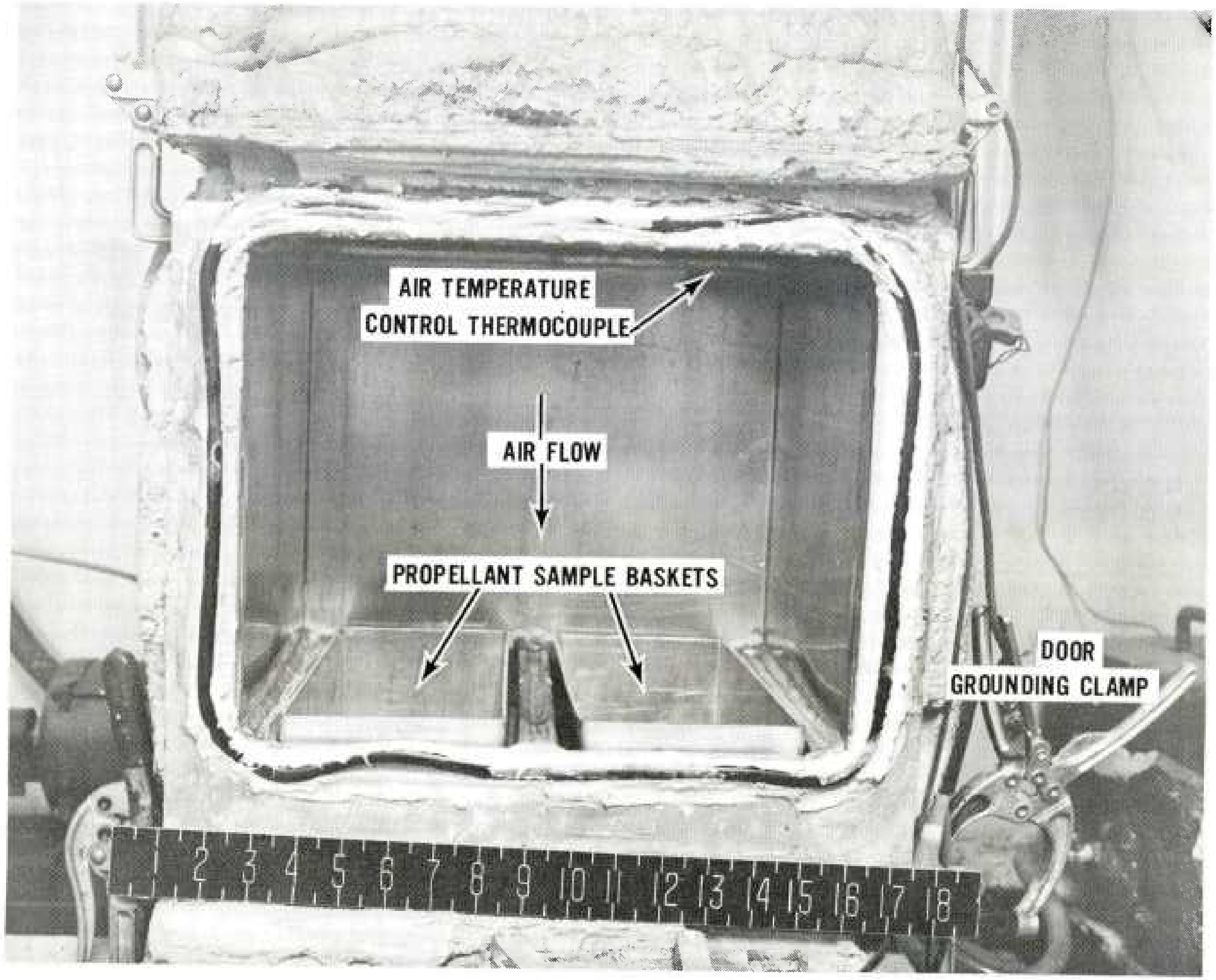


Figure 5. Drying chamber

of a transition from a 10.2 cm (4-inch) round duct to a 0.028 m^3 (1.0 ft^3) chamber. The bottom of this chamber contains two recessed pockets of 0.005 m^3 (0.169 ft^3) each to hold the propellant being dried. The bottom of each pocket is a perforated aluminum plate containing 0.5 cm (3/16-inch) holes on 0.6 cm (1/4-inch) staggered centers. A 25.4 cm (10-inch) transition section below the drying chamber reduces the air discharge to a 7.6 cm (3-inch) pipe connection that is further reduced through PVC pipe and rubber hose (NG hose) to adapt to an existing 5.1 cm (2-inch) stainless steel vent through the bay wall. The front of the drying chamber is sealed during the operation of the unit with a gasketed aluminum door held in place by four quick-release clamps (figure 4). The door was fabricated with the two central cut-out panels covered with aluminum foil to provide pressure relief in the event of a propellant fire within the dryer.

In order to aid in the loading, unloading, and weighing of the propellant during the evaluation runs, two aluminum propellant baskets were fabricated to fit in the drying chamber recesses in such a way as to prevent any by-pass of the drying air around the baskets. These baskets were fabricated with solid sheet sides, open tops and perforated plate bottoms (figure 6). The perforations are 0.3 cm (7/64-inch) located on 0.6 cm (1/4-inch) staggered centers. Each basket has a volume of 0.004 m^3 (0.144 ft^3).

Drying Air Flow Control

An existing Hastings Air Flow Meter (Model AAM-62RX) with a Hastings probe (Type S-22A) inserted in the 10.2 cm (4-inch) line between the air heater and the drying chamber was used to measure and provide air flow control through an existing 1.3 cm (1/2-inch) Foxboro (Type F8) control valve. The cable from the probe was connected to the Hastings Air Meter which was mounted on the wall outside of the operating bay. The meter indicated air flow in feet per minute (fpm) and had a range of 0-1000 fpm (0-472 l/sec). The meter output voltage of 1-5 volts (DC) was fed to a Fisher Electronic Indicating Controller (Model TL-102) which converted the signal to a 4-20 ma signal to control the air flow. A Fisher Electro-Pneumatic Transducer (Type 546) converted the 4-20 ma signal to 122.1-204.8 kPa (3-15 psig) air pressure to operate the flow control valve.

The system was recalibrated using a hand-held Alnor Thermo-Anemometer (Model 8500) with a 0.6 cm (1/4-inch) diameter probe. The original calibration curve was found to be accurate during calibration checks prior to the start of test runs and during the tests. This curve was used for all test runs to set the desired air flow (figure 7).

Since studies of current operations had previously established the desirability of operating the bench-scale dryer at approximately 0.5 l/sec (1.0 SCFM) of air per 0.4 kg (1.0 lb) of

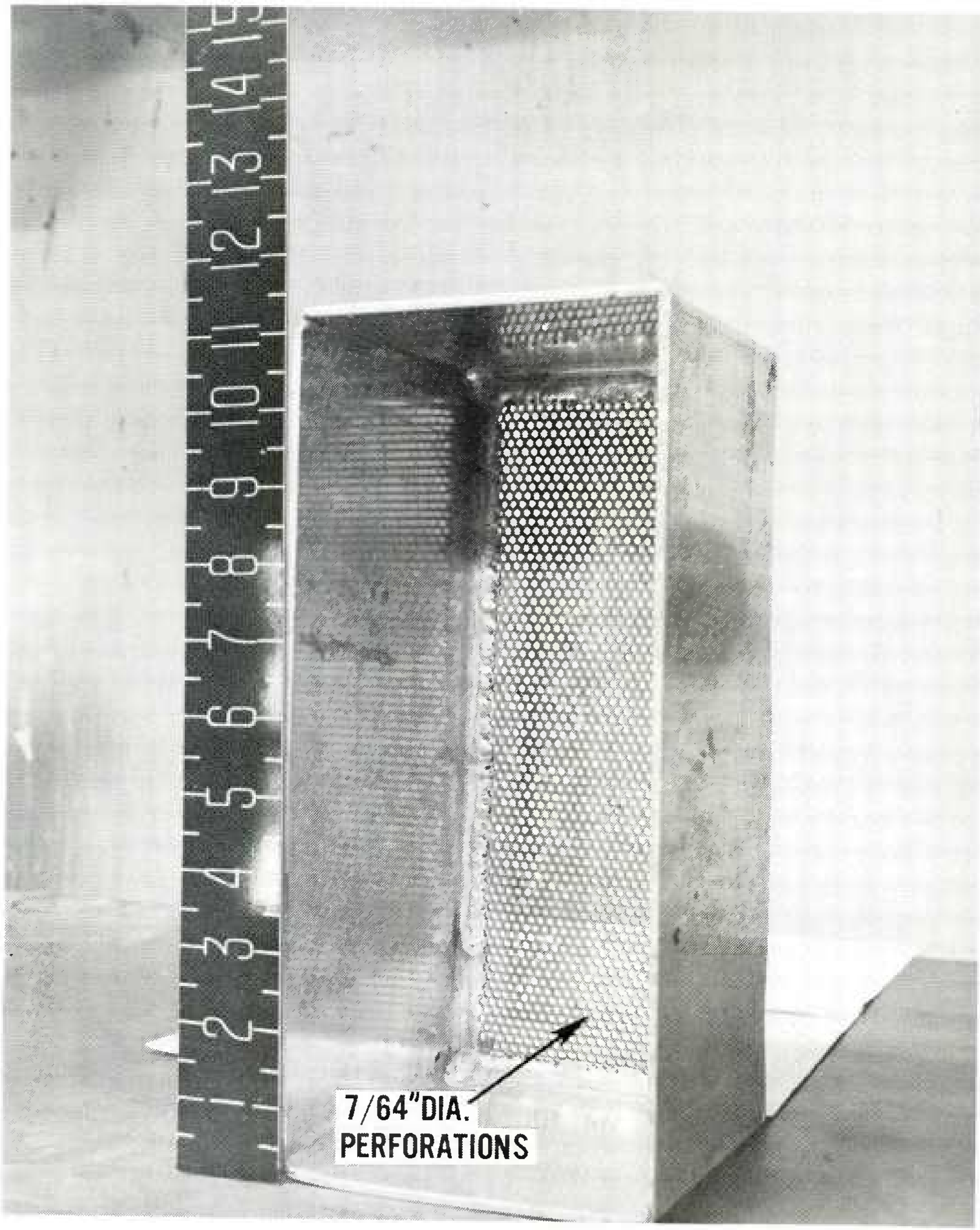


Figure 6. Propellant drying basket

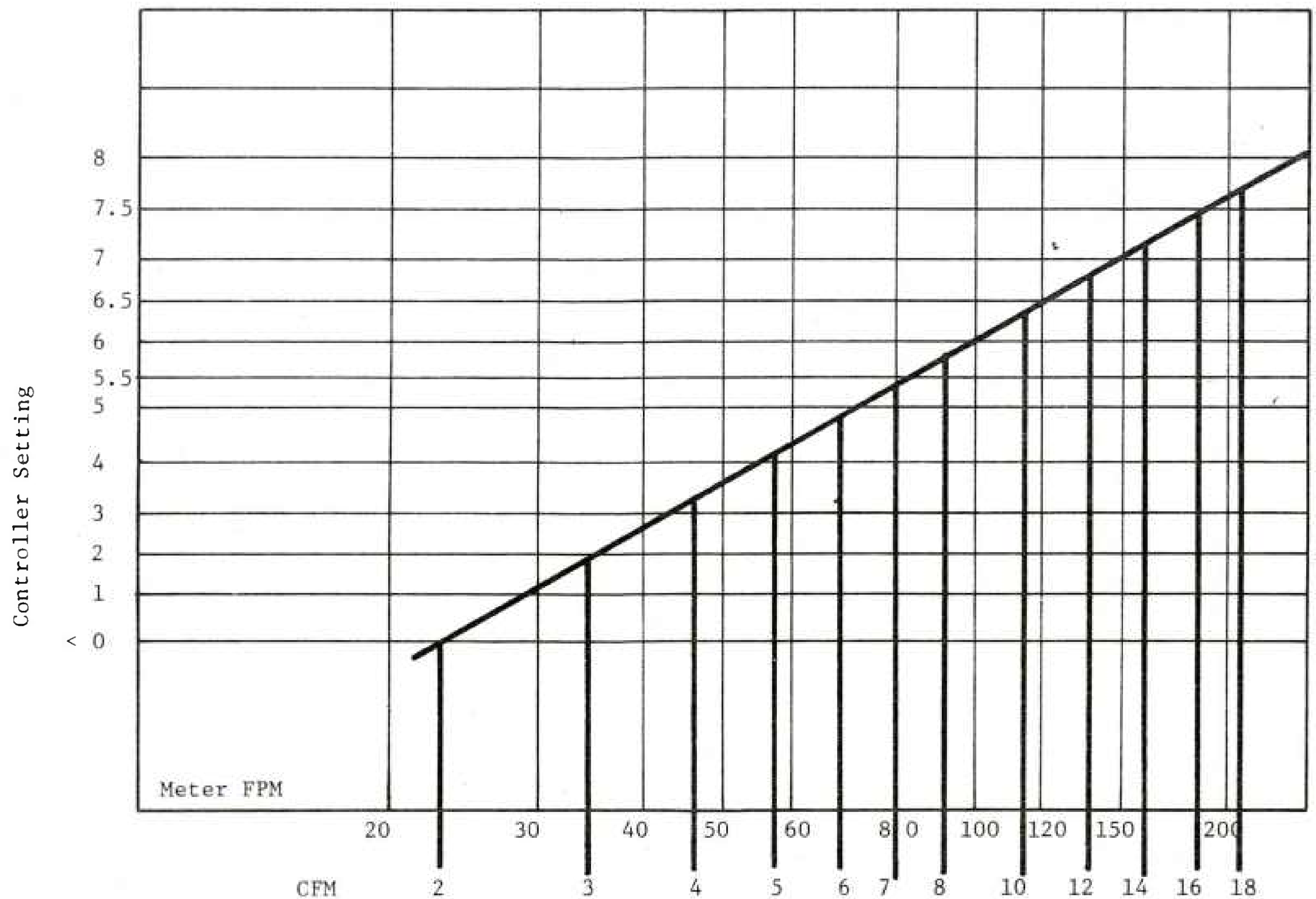


Figure 7. Hastings air flow meter calibration curve

propellant charged, the following calculation was used to establish the desired air flow control setting for each test run, based on variations of operating temperature, barometric pressure, and propellant weight.

Probe location: 10.2 cm (4 inches) pipe between the air heater and drying chamber.

Air temperature: Desired setting for test.

Cross sectional area of flow: $(\pi)(4/2)^2/144 = 8.727 \times 10^{-2}\ ft^2$

Air flow, actual ft^3/min = (Hastings meter reading)(8.727×10^{-2}) ACFM

Air flow, SCFM = (ACFM)(530°R)(Barometer, inch Hg)/(t°F + 460)(29.92)

This reduces to air flow for 1.0 SCFM/lb propellant:
Hastings Meter Setting = (lbs. propellant)(t°F + 460)/(1.546)(Barometer, inch Hg)

Miscellaneous Instrumentation

1. Air Temperature

Two dial thermometers were installed in the air stream to provide a means of monitoring air temperature prior to heating and after leaving the drying chamber. The first was installed in the duct housing the relative humidity sensor and was a Tel-Tru (Model AA5T5R) with a scale of 6.7 to 115.6°C (20 to 240°F). The second was installed in a pipe tee at the outlet of the drying chamber and was a Weston (Model 2261) with a scale of -20 to 110°C (-4 to 230°F).

2. Air Pressure

A Dwyer Instrument Company Magnehelic pressure gauge (Scale 1.2-1.4 WC) was installed in the duct housing of the relative humidity sensor to provide a means of monitoring the back pressure of the air flow through the air heater, drying chamber, and exhaust piping.

Barometric pressures were obtained from calibrated instruments in the RAAP Powder Laboratory and from the Instrument Maintenance Shop.

Air Dehumidification Equipment Survey

Since an existing bench-scale propellant dryer had been selected for modification to provide controlled humidity in the drying air by completely dehumidifying compressed plant air and then rehumidifying the air to the desired level by steam injection, an available Van Air Dryer unit, using Van Air Dry-O-Lite desiccant, was selected for this installation.

A survey of the available types and sizes of air dehumidification systems for prototype studies was conducted. A preliminary Hazards Analysis investigation was conducted on absorptive, adsorption, and condensation-by-cooling (refrigeration) types of systems for moisture removal (Appendix C). This study showed the refrigeration type of dehumidifier to be the most attractive system from a safety standpoint, with the adsorptive and absorptive systems following in that order. However, the refrigeration and several of the adsorptive systems require that the air be compressed to 791.03 kPa (100 psig) or more in order for the system to operate efficiently and still remain in a relatively compact package. The energy required for compression of the air was considered to offset any process conservation of energy that might be attained through dehumidification using these systems.

The continuously regenerated adsorptive system, manufactured by Bry-Air, Incorporated of Sunburry, Ohio, was tentatively selected for the proposed prototype installation. This design was selected on the basis that it operates at atmospheric pressure and can use both the existing open tank air dry blower and 377.24 kPa (40 psig) steam supply for process air flow and regenerative heat, respectively. However, the system requires three to four hours of operation before effective dehumidification can be attained. During subsequent bench-scale testing, it was determined that the portion of the drying cycle in which dehumidification could possibly be effective occurs during the first three to six hours; therefore, the dehumidifier would have to be operated during periods when air is not required for the process in order to provide dry air when required by the process. This is neither cost nor energy efficient and the concept of using dehumidified air is not recommended (see Cost and Energy Analysis, Appendix B).

Waste Heat Recovery Equipment Survey

Since the selection of the bench-scale system provided for very low air flows [2.8-3.8 l/sec (6-8 SCFM)] for propellant drying, it was considered to be impractical to recover waste heat from the dryer exhaust by either recycle or mechanical means. Therefore, no consideration was given to a bench-scale waste heat recovery system. It was, also, considered that the technical data generated in the drying of single-base propellant in the bench-scale equipment under varying conditions of humidity and temperature would provide the necessary information for the design of a heat recovery and/or recycle system for a prototype installation.

A survey was conducted of the available types and sizes of air-to-air heat recovery equipment with emphasis on the heat pipe and plate-type modes of recovery.

Operating data was given to two heat pipe and one plate type fabricator of heat recovery equipment for rough order of magnitude (ROM) equipment cost and performance data. ROM costs were received from all three vendors and operating efficiencies (theoretical computer processing) from Q-Dot Corporation (heat pipe) and Des Champs Laboratories, Incorporated (Z Duct plate). The second supplier of heat pipes was not queried further for operating efficiencies because of a much higher ROM cost estimate than Q-Dot or Z Duct.

The Q-Dot heat pipe works on the principle of boiling and condensing Freon sealed in finned tubes and has a claimed heat recovery efficiency of 60.5 percent, based on dry air. This efficiency will be somewhat higher, but probably not in excess of 65 percent, if the calculation had been based on humid air.

The Z Duct is simply an accordion fold of aluminum sheet metal to form a continuous series of plates between the hot exhaust air and the cold supply air. Heat recovery efficiency of this unit is claimed to be 76 percent, based on humid air, but at a minimum will not drop below 68 percent.

Basic equipment (approximately $6,000) is cost competitive for either unit selected. However, either unit would incur some increase in fabrication cost to meet safety standards. The Z Duct appears to be the more acceptable design by reason of higher energy recovery efficiency and the undesirability of having an expanded fit fin tube system as would be found in the Q-Dot. Both systems can be washed out, but the close spacing of the Q-Dot tube fins will make the unit more difficult to clean.

Based on the computer calculation from Z Duct of 23.95 kg - cal/sec (337,096 Btu/hr) energy savings per open tank air dry will be attained. Using 377.24 kPa (40 psig) steam at a RAAP 1980 cost of $0.0095/kg ($4.320/1,000 lbs), and an effective energy recovery period of 7 hours per drying cycle (see description of temperature cycle under the Current Operations section of this report), annual savings of 679,433 kg (1.498×10^6 lb) of steam and $6471/air dry tank will be realized by installing Z Duct energy recovery units.

A preliminary Hazards Analysis study of the Z Duct is presented in Appendix D. Additional design review and safety approvals will be required prior to procurement and installation of this equipment in open tank air dry service.

BENCH-SCALE STUDIES

Test Plan

A proposed test plan for the bench-scale propellant drying studies was devised as a guideline prior to performing the studies (figure 8). The plan was modified during the studies (figure 9) as the initial test results indicated the more pertinent data collection required to complete this study in an economical and expeditious manner. Difficulty in setting relative humidity controls resulted in slight variations from the amended plan conditions (parenthetical numbers shown on figure 9), but this is not considered pertinent to the end results and conclusions drawn from the study.

Test Propellant

Source

M6MP f/155-mm single-base propellant was obtained for each test from the production line at the wet-screen house operation, just prior to charging into the open tank air dry. The propellant was sealed in plastic sample bags to prevent loss of moisture before charging to the bench-scale dryer.

Charge Weight

The test charge was divided equally into the two aluminum baskets (figure 6) and weighed to the nearest ounce (oz) on a calibrated platform scale which has a range of 0 to 242.51 kg (0 to 110 lb). Total propellant weights varied from 13.503 to 22.873 kg (6.125 to 10.375 lb), depending on the quantities furnished by the production line.

At the conclusion of each run, the propellant was reweighed and the weights used to determine a quick material balance to check the validity of moisture removal calculations.

Propellant Sampling

Propellant samples were taken from the two sample baskets at the start and periodically throughout each drying cycle for laboratory determination of moisture, ethyl alcohol, and diethyl ether. Each sample was comprised of approximately 8 grams (g) taken randomly from the baskets at top, middle, and bottom locations. Tweezers were used to handle the propellant granules to eliminate the possibility of changing the granule moisture content by contact with glove material.

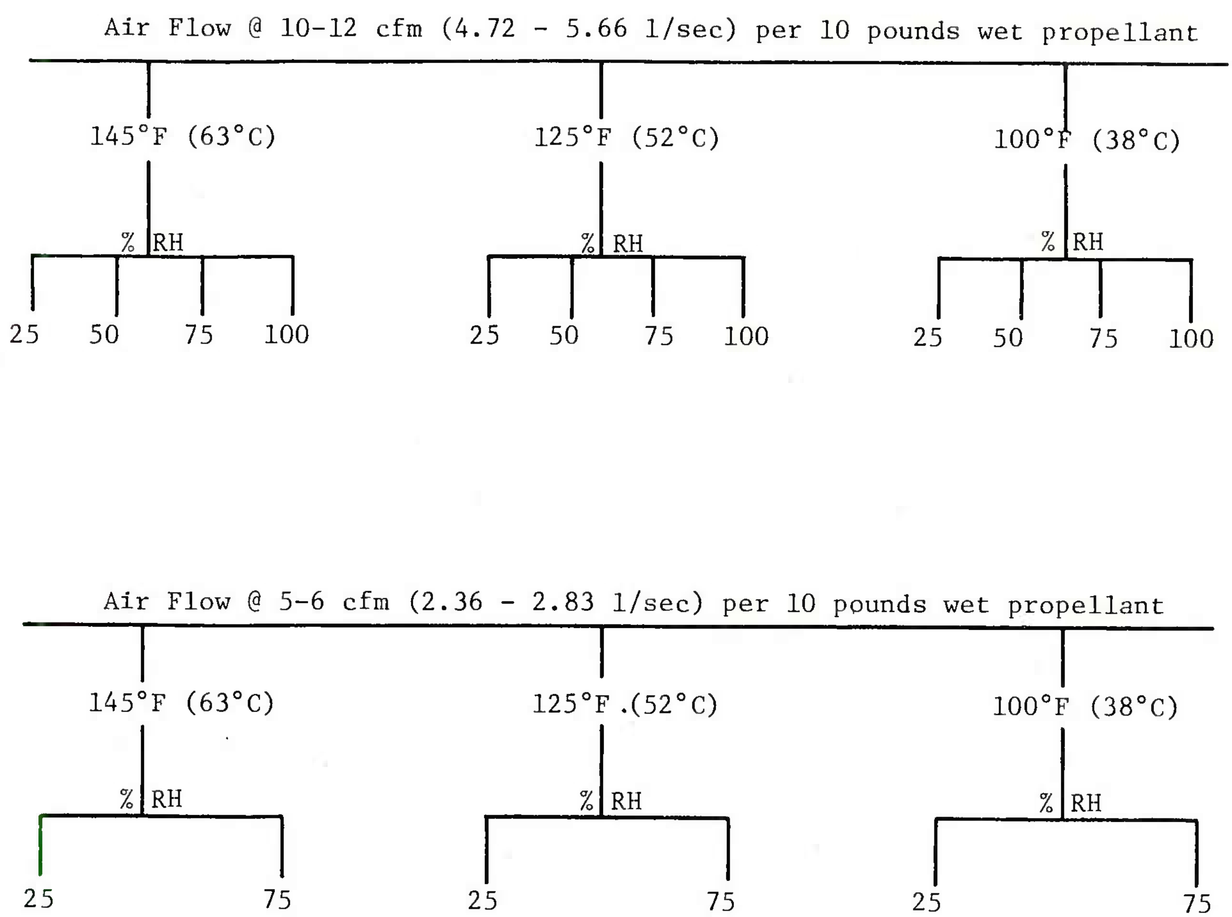
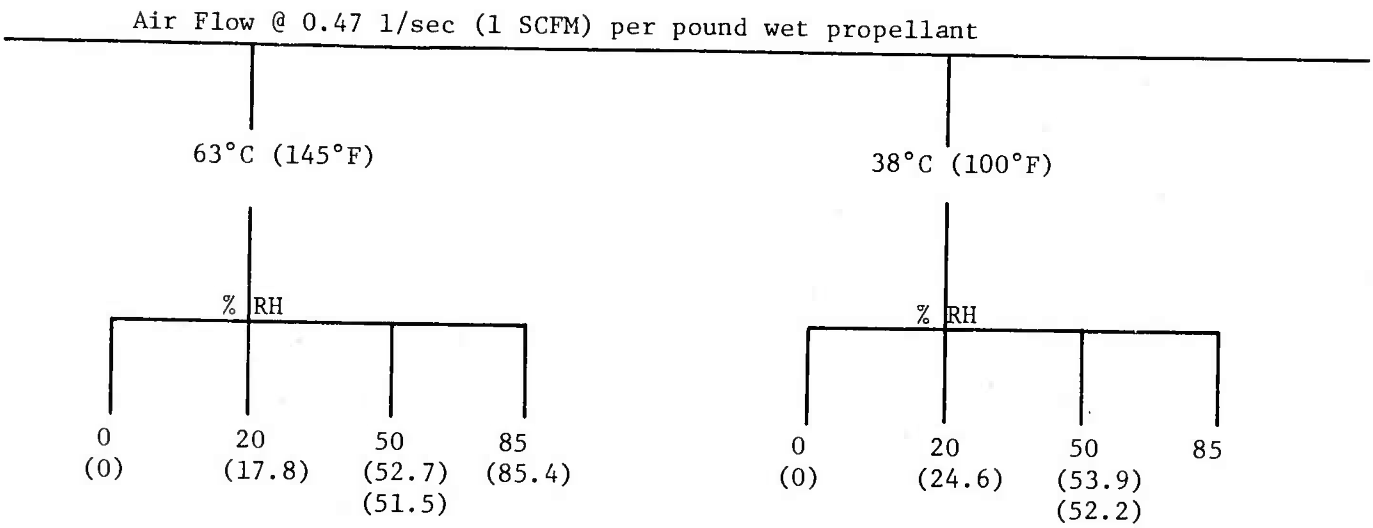


Figure 8. Bench-scale dryer test plan
M6 MP f/155-mm single-base propellant



( ) Indicates actual tests conducted.

Figure 9. Amended bench-scale dryer test plan
M6 MP f/155-mm single-base propellant

The sample granules were immediately placed in a preweighed, 125 ml flask containing 50 ml of a mixture of methyl ethyl ketone and secondary butyl alcohol, and tightly stoppered. Sample weights were determined by the analytical laboratory and reported for use in material balance checks.

Analytical Testing

The propellant samples were analyzed for moisture, ethyl alcohol, and diethyl ether in the RAAP analytical laboratory. The procedure used was Method T103.5.1, "Total Volatiles (Gas Chromatographic Method)," from Standard MIL-STD-286B.

Air Drying Test Procedure

The air flow, temperature, and relative humidity conditions for each test were established and the bench-scale dryer was allowed to warm up to the desired drying temperature (usually overnight). The propellant was weighed into the aluminum baskets, barometric pressure was obtained from the Laboratory or Instrument Shop, the required air flow then calculated, and the controller adjusted.

$$\text{Hastings Air Meter Setting*} = \frac{(\text{lb propellant})(t°F + 460)}{(1.546)(\text{Barometer, " Hg})}$$

*See Engineering Studies, Drying Air Flow Control, for derivation and controller calibration.

The propellant loaded baskets were then sampled and placed in the drying chamber. The drying chamber was opened during each test only long enough to pull periodic samples for laboratory analysis. Air flow, drying chamber temperature, and air relative humidity were adjusted as needed to hold steady operating conditions during each test.

The following data were recorded periodically during each test and averaged for reporting test results:

Air flow, feet per minute
Oven temperature, °F
Oven exhaust temperature, °C
Ambient air temperature, °F
Ambient air relative humidity, %
Inlet air pressure, inches water
Barometric pressure, inches Hg
Steam pressure, psig
Gross weight of propellant at start, pounds
Gross weight of propellant at end, pounds
Propellant sample weights, grams
Propellant analyses, wt. %

These data were used in calculations and test assessments. Only that required for test definition is presented herein.

Drying Tests

A total of nine test runs were made in the bench-scale dryer. Five tests were conducted at approximately 63°C (145°F) with varying ambient air relative humidities and four tests were made at approximately 38°C (100°F) with varying ambient air relative humidities. Operating and analytical data for these runs are presented in tables 2 through 10. Drying curves are shown in figures 10 through 20. Test data from one run at 38°C (100°F) and 53 percent RH (run 5) was not used in calculations because of extreme variations in ambient temperature and operating problems during the test. However, another test was conducted at these conditions and the data assessment is included.

A high relative humidity (85 percent) test was not conducted at the lower temperature level 38°C (100°F) because of the evidence generated in lower humidity ranges that indicated the impracticality of operating at this condition.

Runs 1 through 4 and run 9 were conducted at the higher temperature (63°C/145°F) and ambient air relative humidities of zero percent to 85 percent. Run 4 was conducted as a recheck of run 1 to verify baseline data.

Runs 5 through 8 were conducted at the lower temperature (38°C/100°F) and ambient air relative humidities of zero percent to 54 percent. Run 6 was a retest of run 5 in which difficulties were encountered, as previously mentioned.

Drying Test Results

Review of the analytical data from all nine runs confirms preliminary laboratory test data which indicated that alcohol and ether are not further removed from the propellant during the air dry operation (tables 2A through 10A).

The first test run was conducted at the current production operating temperature [63°C (145°F)] and at a relative humidity near midrange (53 percent) to establish baseline data (table 2, figure 10). This test was repeated in run 4 (table 5, figure 13) to confirm the data, as there was some question of the sampling technique during the first tests. These two tests show good correlation to the average production cycle of 12 hours of heated air dry time. Therefore, the bench-scale dryer results should be considered reasonably close to those obtained in full-scale operation of the open tank air dry units.

Table 2. Bench-scale dryer - Run No. 1 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air Flow, l/sec (SCFM)/lb propellant	0.47	(1.0)
Oven Temperature, °C (°F)	63	(145)
Ambient Air Temperature, °C (°F)	22	(71)
Ambient Air Relative Humidity, percent	53	
Barometric Pressure, mm Hg (inches Hg)	711.9	(28.03)

Table 2A. Bench-scale dryer - Run No. 1 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying Hours	Residual Moisture (percent)	Alcohol (percent)	Ether (percent)
0	6.59	0.23	1.29
3	2.12	0.24	1.41
6	1.54	0.24	1.41
9	0.82	0.24	1.45
12	0.59	0.23	1.41
14	0.40	0.23	1.39

Table 3. Bench-scale dryer - run 2 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air Flow, l/sec. (SCFM)/lb propellant	0.38	(0.8)
Oven Temperature, °C (°F)	62	(144)
Ambient Air Temperature, °C (°F)	30.3	(86)
Ambient Air Relative Humidity, percent	85	
Barometric Pressure, mm Hg (inches Hg)	712.6	(28.06)

Table 3A. Bench-scale dryer - run 2 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying Hours	Residual Moisture (percent)	Alcohol (percent)	Ether (percent)
0	7.51	0.15	0.83
3	2.69	0.14	0.90
6	2.12	0.12	0.88
9	1.52	0.14	0.93
12	1.15	0.11	0.87
14	1.12	0.12	0.88

Table 4. Bench-scale dryer - run 3 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air Flow, 1/sec. (SCFM)/lb propellant	0.38	(0.8)
Oven Temperature, °C (°F)	63	(146)
Ambient Air Temperature, °C (°F)	23	(73)
Ambient Air Relative Humidity, percent	18	
Barometric Pressure, mm Hg (inches Hg)	717.0	(28.23)

Table 4A. Bench-scale dryer - run 3 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying Hours	Residual Moisture (percent)	Alcohol (percent)	Ether (percent)
0	6.84	0.11	0.83
3	2.64	0.13	0.84
6	1.89	0.11	0.84
9	1.26	0.13	0.98
12	0.85	0.12	0.90
14	0.75	0.12	0.82

Table 5. Bench-scale dryer - run 4 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air Flow, l/sec (SCFM/lb propellant	0.47	(1.0)
Oven Temperature, °C (°F)	63	(145)
Ambient Air Temperature, °C (°F)	20	(68)
Ambient Air Relative Humidity, percent	52	
Barometric Pressure, mm Hg (inches Hg)	719.3	(28.32)

Table 5A. Bench-scale dryer - run 4 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying Hours	Residual Moisture (percent)	Alcohol (percent)	Ether (percent)
0	6.97	0.09	0.96
3	2.52	0.08	0.98
6	1.71	0.09	1.01
9	0.98	0.09	0.92
10	0.86	0.09	0.93
12	0.65	0.08	0.92
14	0.53	0.08	0.91

Table 6. Bench-scale dryer - run 5 operating conditions, controlled humidity air for dyring M6MP f/155-mm single-base propellant

	Average	
Air Flow, 1/sec (SCFM)/lb propellant	0.47	(1.0)
Oven Temperature, °C (°F)	37	(99)
Ambient Air Temperature, °C (°F)	18	(64)
Ambient Air Relative Humidity, percent	54	
Barometric Pressure, mm HG (inches Hg)	7.7.0	(28.23)

Table 6A. Bench-scale dryer - run 5 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying Hours	Residual Moisture (percent)	Alcohol (percent)	Ether (percent)
0	6.39	0.06	0.97
3	3.77	0.09	0.97
6	3.01	0.08	0.98
9	2.82	0.08	1.00
9 3/4	2.65	0.09	0.96
11	2.43	0.09	1.02
12	2.24	0.08	1.00
14	2.30*	0.09	0.99

*Lost heat during last hour of run, due to steam trap freeze-up.

Table 7. Bench-scale dryer - run 6 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air flow, l/sec (SCFM)/lb propellant	0.47	(1.0)
Oven temperature, °C (°F)	38	(101)
Ambient air temperature, °C (°F)	23	(73)
Ambient air relative humidity, percent	52	
Barometric pressure, mm Hg (inches Hg)	715.1	(28.16)

Table 7A. Bench-scale dryer - run 6 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying hours	Residual moisture (percent)	Alcohol (percent)	Ether (percent)
0	5.46	0.28	1.82
3	2.89	0.31	1.81
6	2.68	0.31	1.75
7	2.60	0.29	1.69
9	2.34	0.29	1.85
12	2.09	0.32	1.87
14	1.95	0.30	1.82
24	1.28	0.30	1.87

Table 8. Bench-scale dryer - run 7 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air flow, l/sec (SCFM)/lb propellant	0.47	(1.0)
Oven temperature, °C (°F)	39	(103)
Ambient air temperature, °C (°F)	25	(76)
Ambient air relative humidity, percent	25	
Barometric pressure, mm Hg (inches Hg)	718.5	(28.29)

Table 8A. Bench-scale dryer - run 7 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying hours	Residual moisture (percent)	Alcohol (percent)	Ether (percent)
0	5.83	0.29	1.77
3	2.95	0.30	1.86
6	2.25	0.31	1.82
7	2.08	0.30	1.88
9	1.94	0.33	1.95
12	1.68	0.27	1.84
14	1.57	0.29	1.86
24	1.17	0.31	1.93

Table 9. Bench-scale dryer - run 8 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air flow, l/sec (SCFM)/lb propellant	0.44	(0.94)
Oven temperature, °C (°F)	41	(105)
Ambient air temperature, °C (°F)	23	(73)
Ambient air relative humidity, percent	0	
Barometric pressure, mm Hg (inches Hg)	722.7	(28.45)

Table 9A. Bench-scale dryer - run 8 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying hours	Residual moisture (percent)	Alcohol (percent)	Ether (percent)
0	6.35	0.20	1.35
2	3.12	0.21	1.38
4	3.05	0.21	1.37
6	2.46	0.21	1.42
9	2.03	0.22	1.41
12	1.70	0.20	1.38
14	1.43	0.21	1.41

Table 10. Bench-scale dryer - run 9 operating conditions, controlled humidity air for drying M6MP f/155-mm single-base propellant

	Average	
Air flow, l/sec (SCFM)/lb propellant	0.41	(0.88)
Oven temperature, °C (°F)	63	(145)
Ambient air temperature, °C (°F)	18	(65)
Ambient air relative humidity, percent	0	
Barometric pressure, mm Hg (inches Hg)	722.4	(28.44)

Table 10A. Bench-scale dryer - run 9 analytical data, controlled humidity air for drying M6MP f/155-mm single-base propellant

Drying hours	Residual moisture (percent)	Alcohol (percent)	Ether (percent)
0	7.41	0.21	1.33
2	2.34	0.20	1.43
4	1.83	0.22	1.45
6	1.36	0.22	1.37
9	0.68	0.22	1.38
12	0.35	0.19	1.36
14	0.18	0.18	1.37

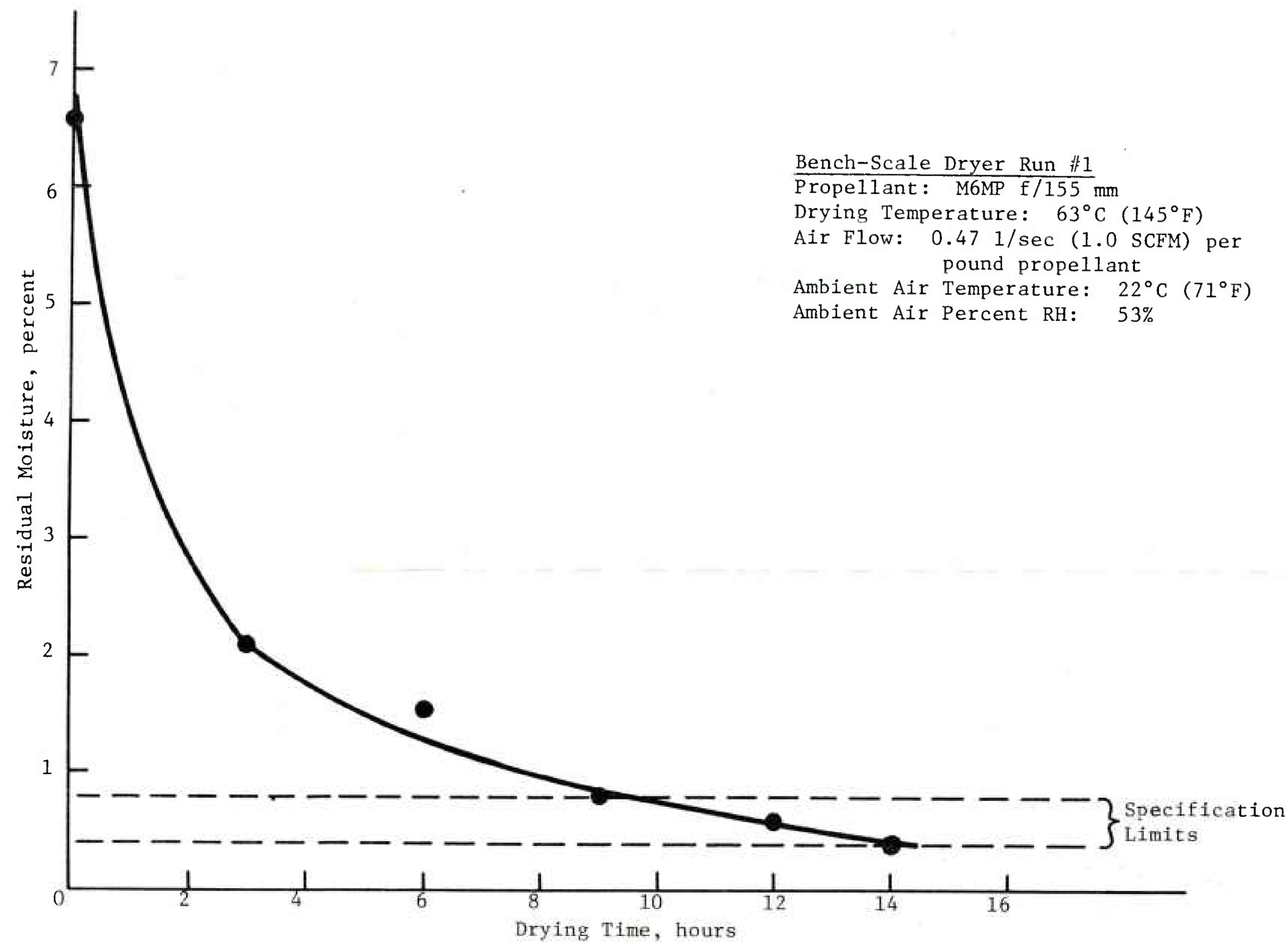


Figure 10. Residual moisture versus drying time - Run No. 1

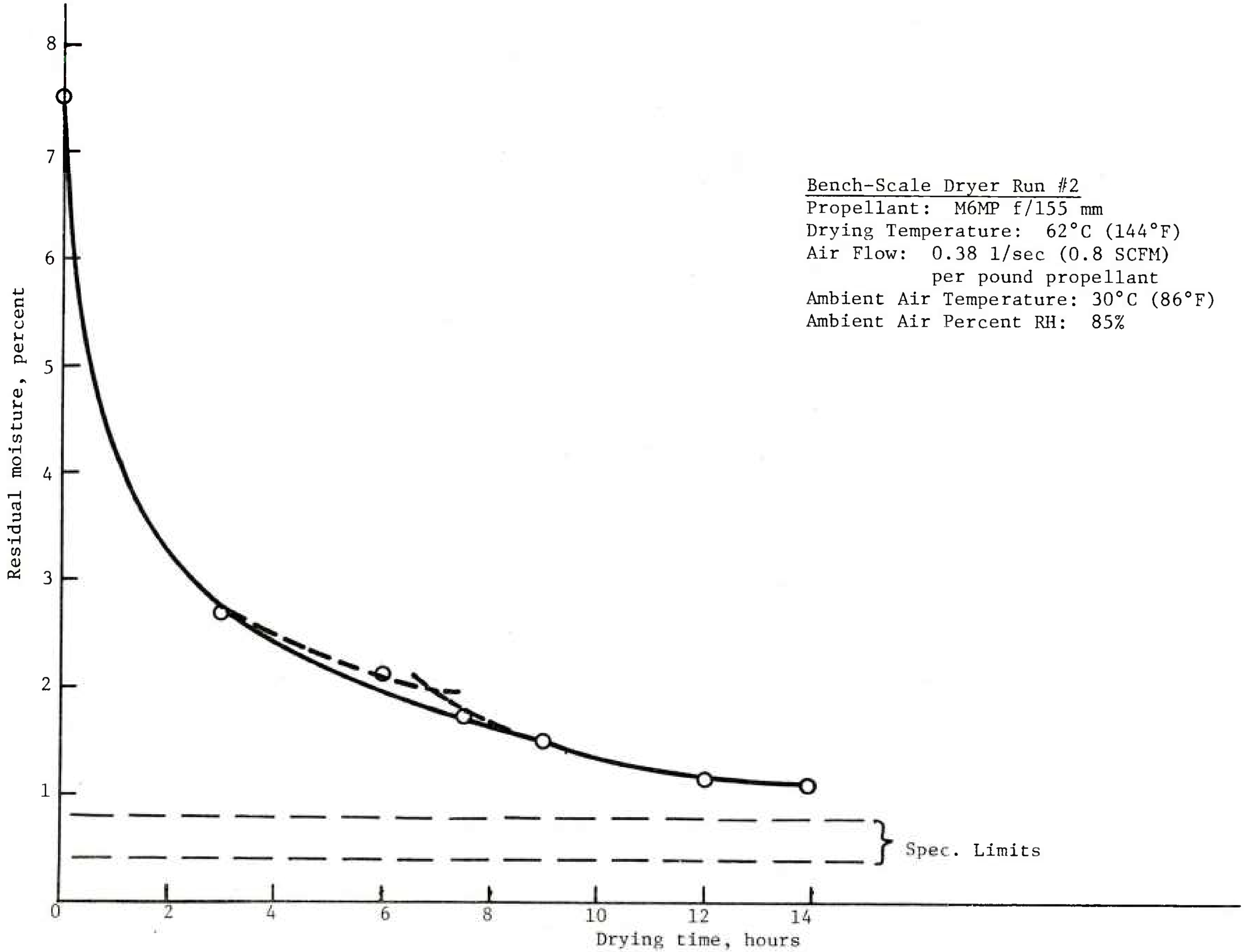


Figure 11. Residual moisture versus drying time - Run No. 2

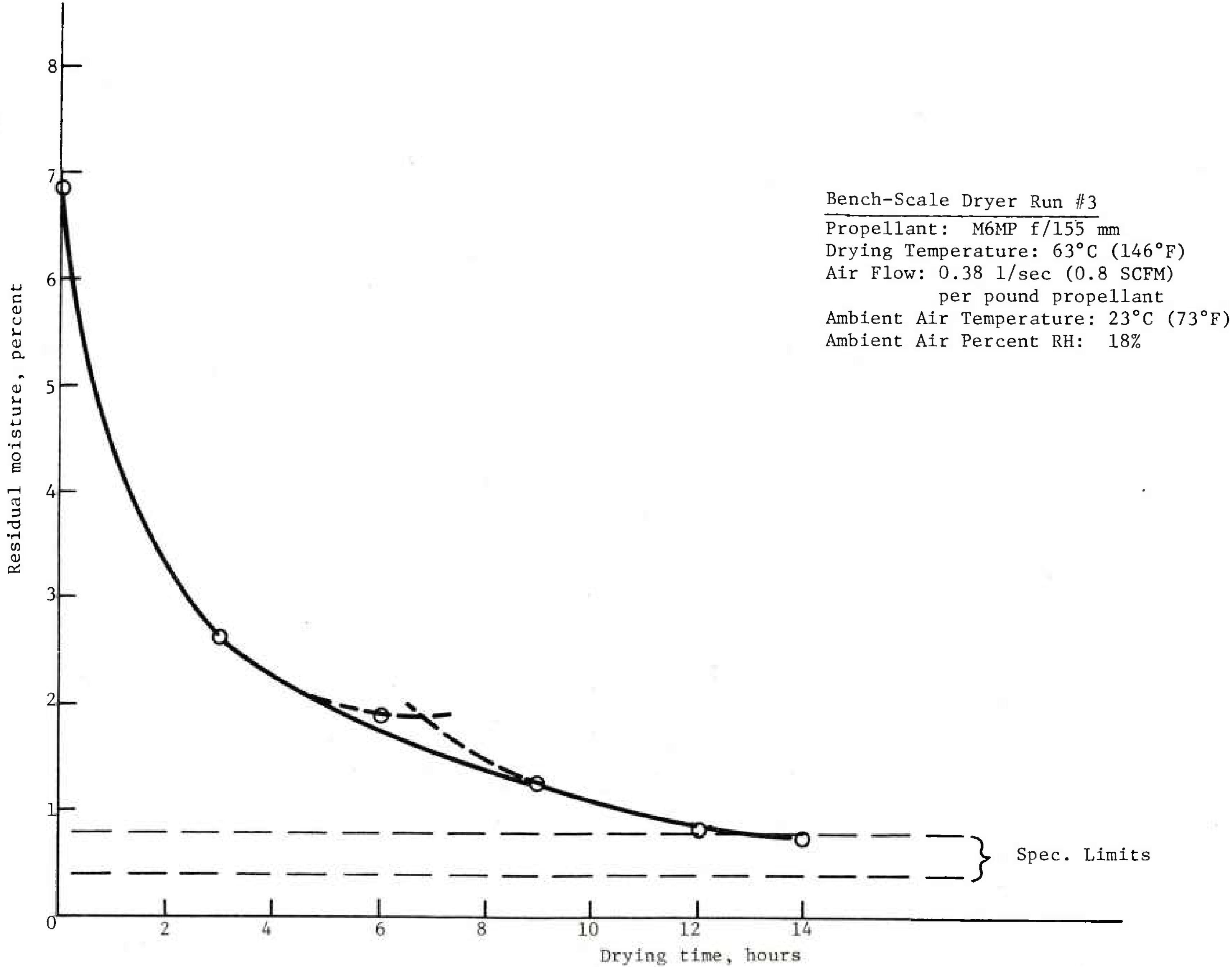


Figure 12. Residual moisture versus drying time - Run No. 3

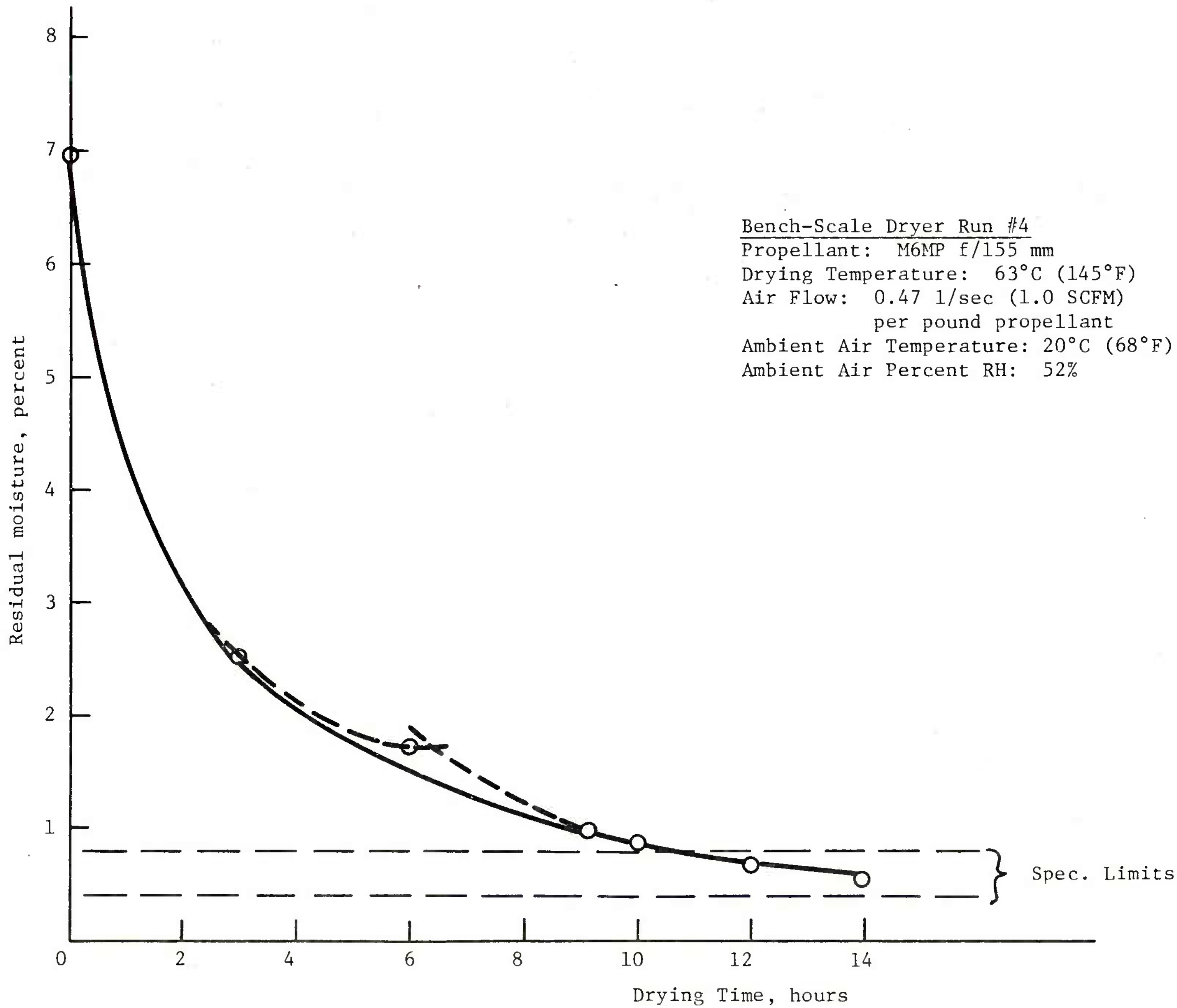


Figure 13. Residual moisture versus drying time - Run No. 4

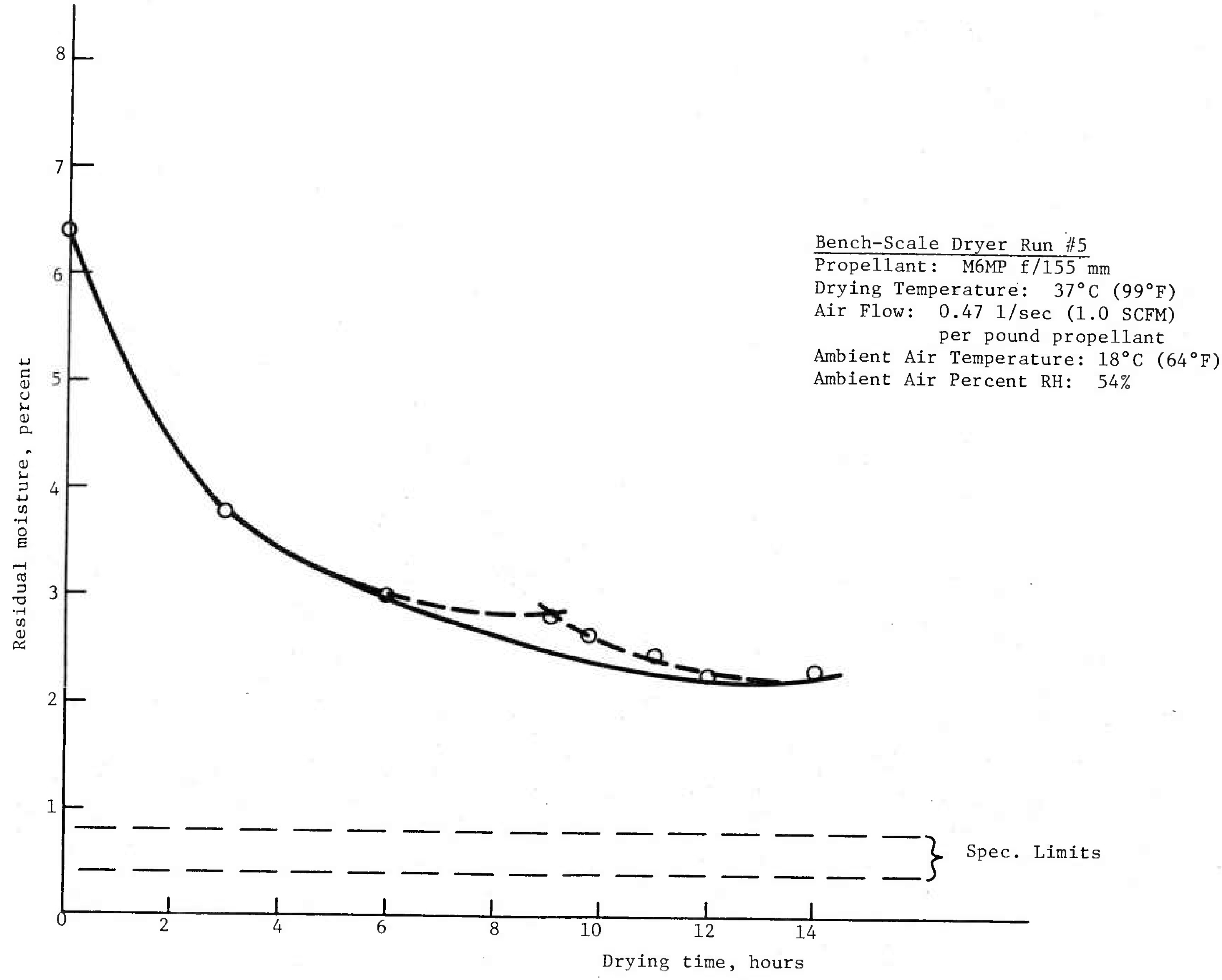


Figure 14. Residual moisture versus drying time - Run No. 5

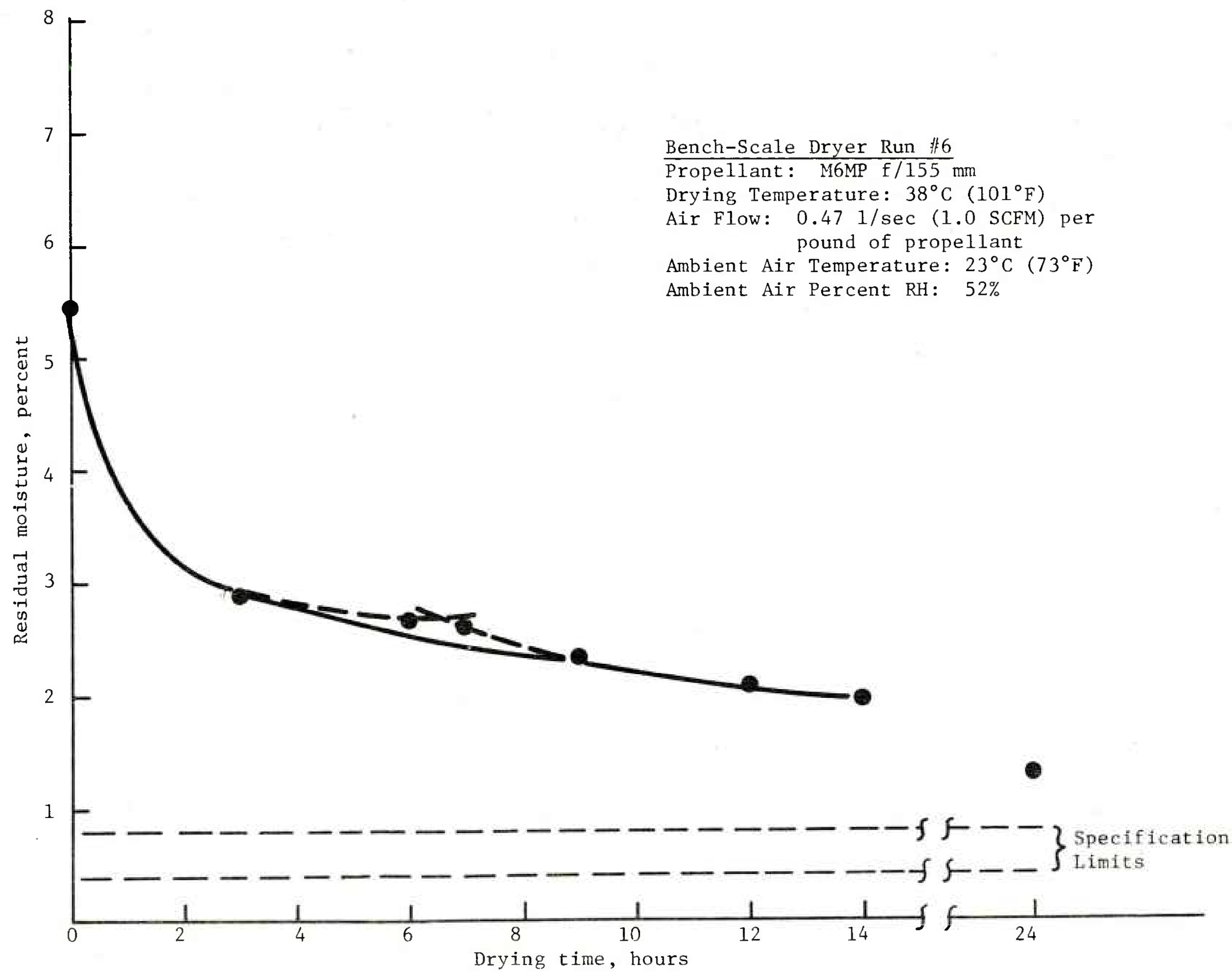


Figure 15. Residual moisture versus drying time - Run No. 6

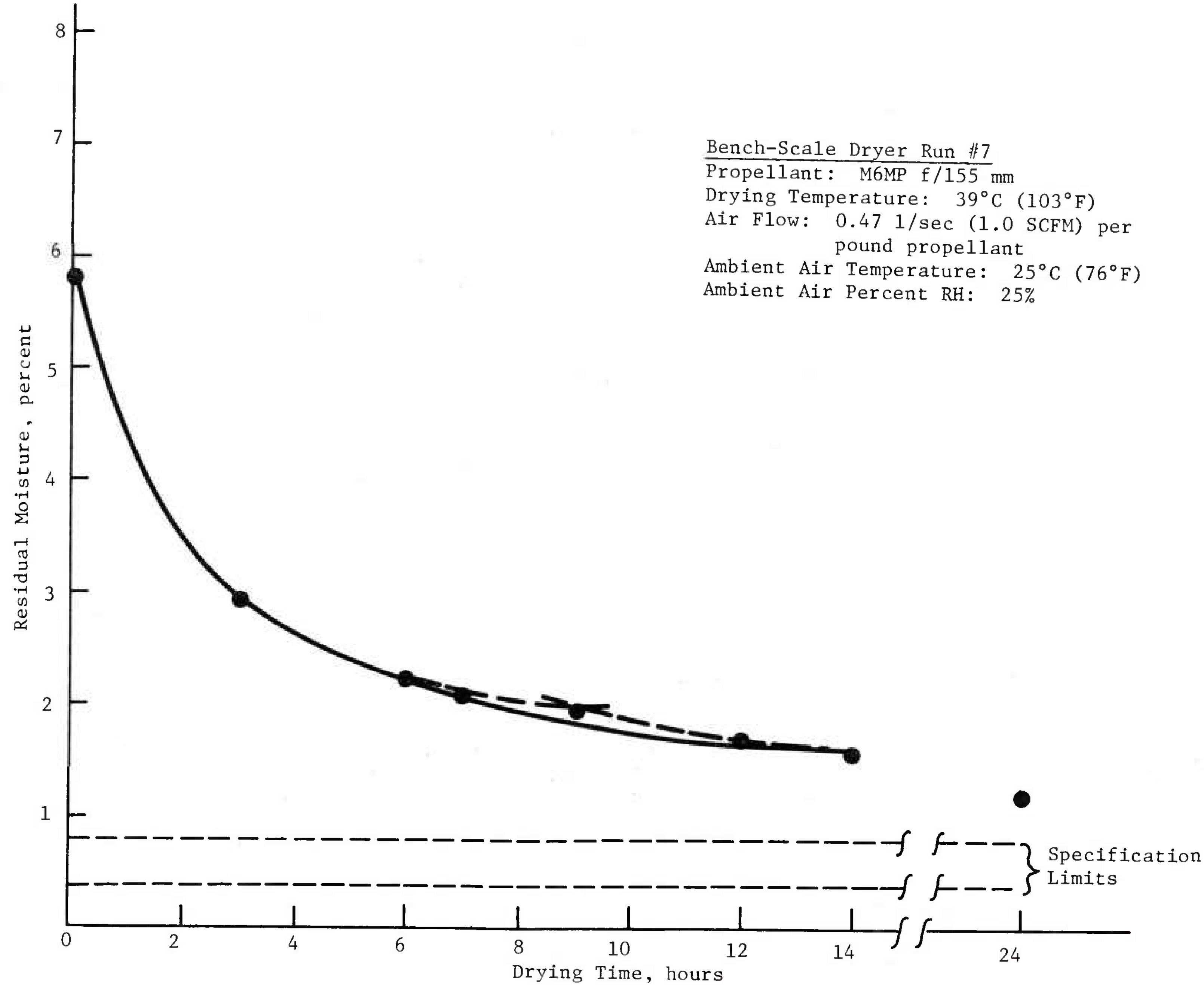


Figure 16. Residual moisture versus drying time - Run No. 7

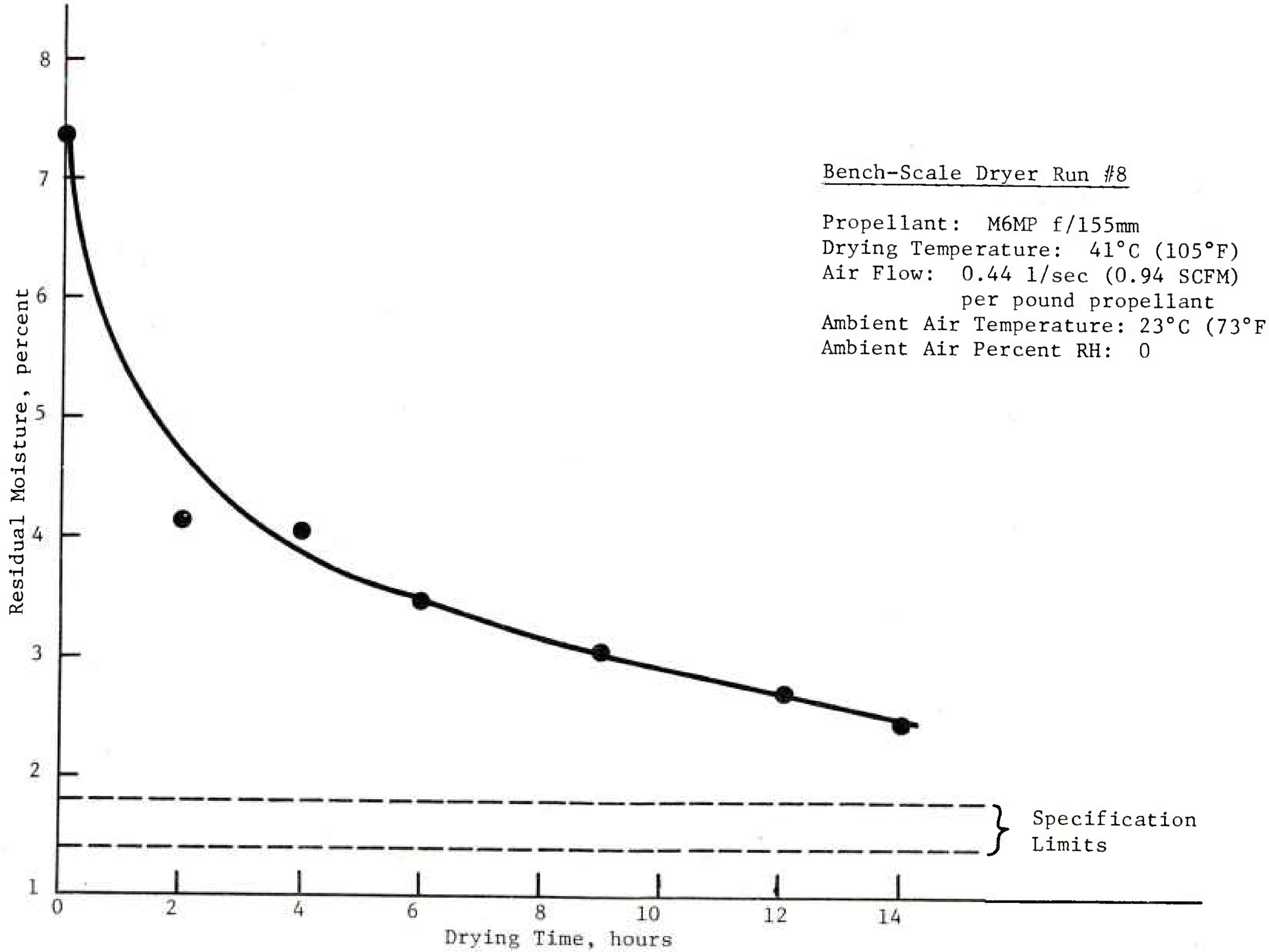


Figure 17. Residual moisture versus drying time - Run No. 8

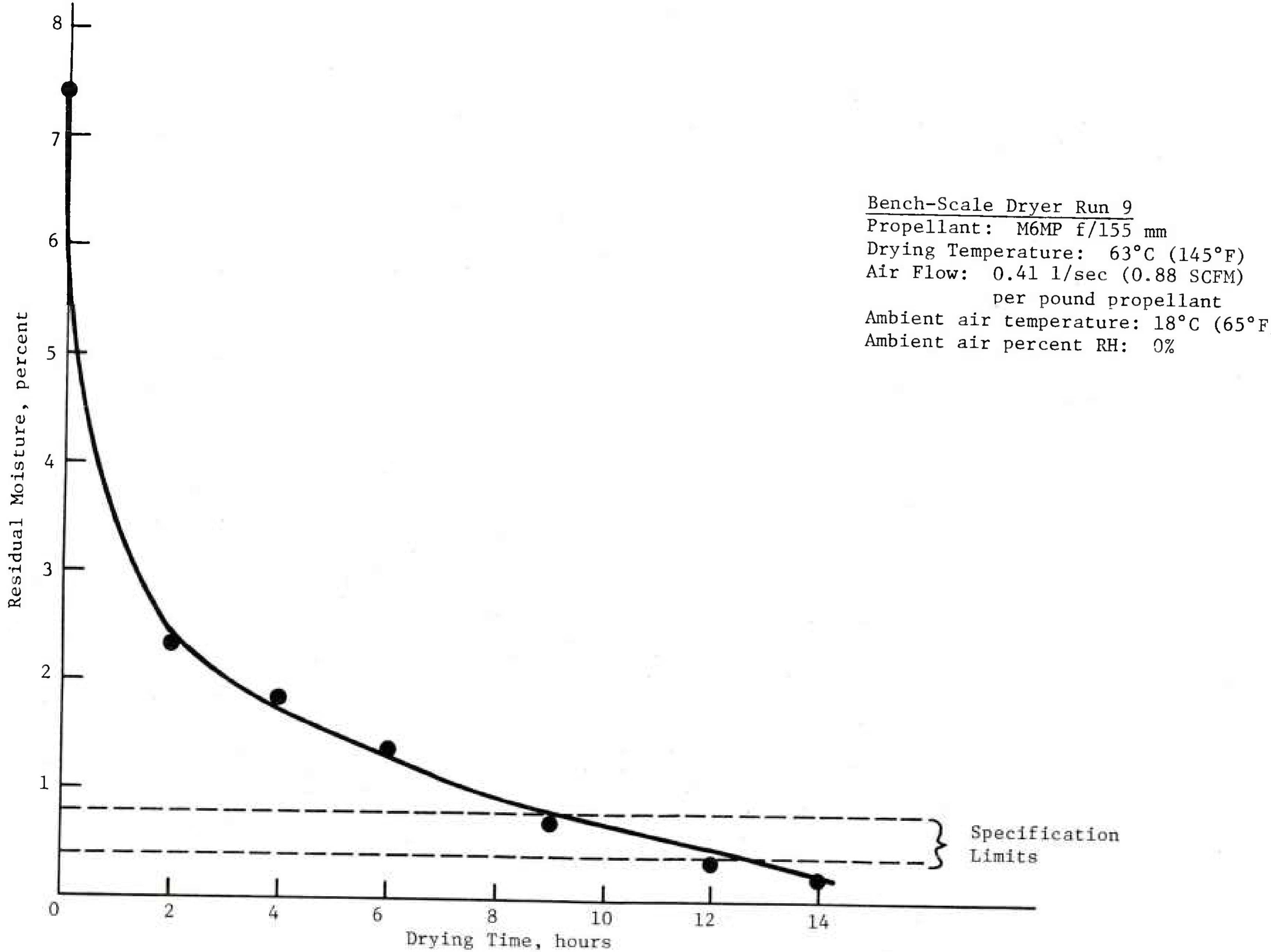


Figure 18. Residual moisture versus trying time - Run No. 9

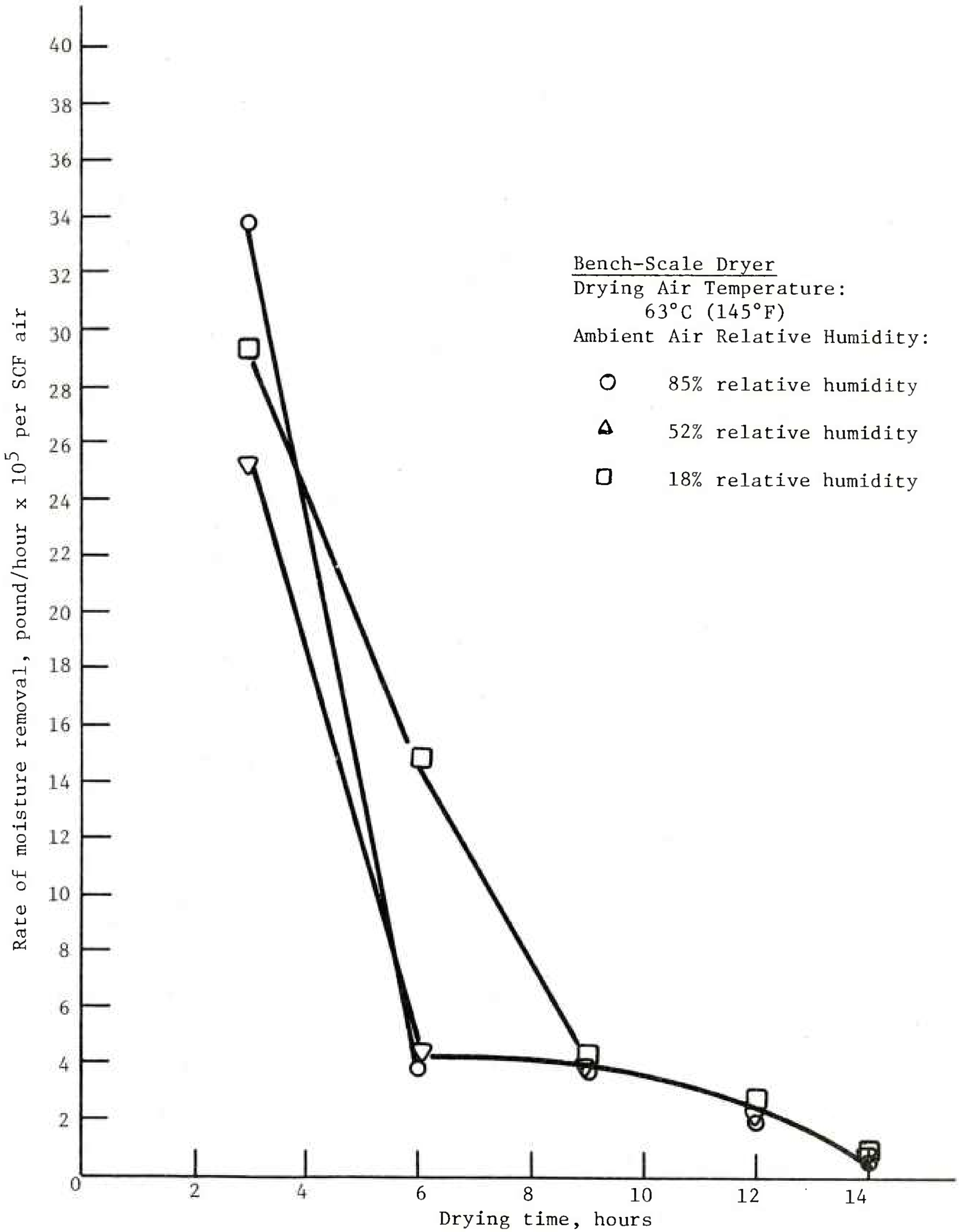


Figure 19. M6MP f/155-mm rate of moisture removal versus drying time for varying relative humidities

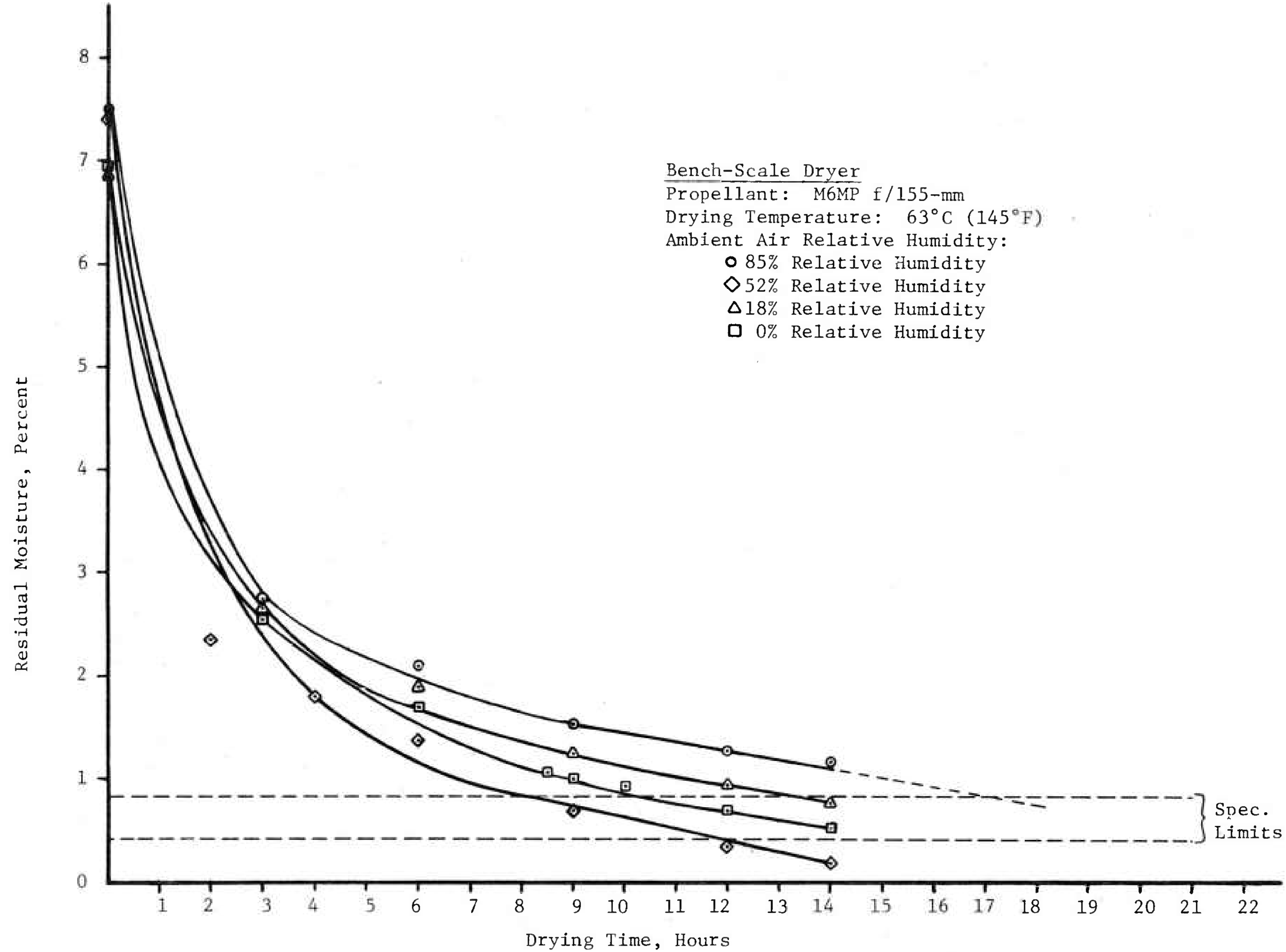


Figure 20. Residual moisture versus drying time

Test runs 2 and 3 were conducted with 63°C (145°F) drying air heated from ambient air conditioned to 85 and 18 percent relative humidities, respectively. These two tests were conducted with the same drying air flow rate as for the baseline test (run 1). However, due to a larger propellant charge to the drying oven, the air-to-propellant ratio was reduced from 0.47 l/sec (1.0 SCFM) to 0.38 l/sec (0.8 SCFM) per pound of propellant. The test data and analytical results are shown in tables 3 and 4, and the drying curves are depicted on figures 11 and 12. At the 85 percent relative humidity level, the drying curve tapered off above the specification residual moisture limits; whereas, at 18 percent relative humidity, the drying curve extended to the desired level of residual moisture. It should be noted that these two curves failed to bracket the baseline curve as expected; therefore, run 4 (table 13, figure 13) was conducted to recheck the baseline data. Since this test reaffirms the original results, the shift in the drying curve is attributed to the reduced air-to-propellant ratio for runs 2 and 3. Calculation of the rate of moisture removal per standard cubic foot of moist air for the three conditions of relative humidity yields a reasonable correlation (figure 19) between the tests, with only the three- to six-hour period showing any advantage for dehumidified air, and that advantage only at a high degree of dehumidification. These data show that the rate of moisture removal falls off sharply after the first three hours, and that the drying of this propellant is essentially on the falling rate segment of the drying curve. The drying rate across this segment of the curve is controlled by the diffusion of moisture from within the propellant grain to the surface and humidity of the air has little effect on the drying rate unless the equilibrium moisture level between the propellant and the drying air is exceeded.

It should be noted that in each of these four test runs, the six-hour residual moisture point falls well above the average drying curve. However, if two segments of the falling rate drying curves are assumed (dotted lines on figures 11 through 13), then a breakpoint is established where humidity ceases to have an effect and internal diffusion becomes controlling. This point is also illustrated in figure 19, where a sudden change can be seen in the drying rate curves with the curves flattening out and coming together regardless of the relative humidity. However, again, the relative humidity does not affect the initial drying rate significantly unless the air is relatively dry and even then shows no effect during the final segment of the curve.

Test run 5 was conducted to determine the propellant drying characteristics at 38°C (100°F) and a relative humidity of the ambient air of approximately 50 percent (actually 54 percent). The data for this test are presented in table 6 and the drying curve in figure 14. These results indicate that the specified residual moisture of 0.8 percent (maximum) will not be attained under these drying conditions. However, the validity of this test is suspect because of rapid changes in atmospheric pressure and ambient temperature during the test. Also, failure was experienced in the drying air heating unit (steam trap freezing) toward the end of the run.

Test runs 6 and 7 (tables 7 and 8, figures 15 and 16) were conducted to determine the propellant drying characteristics at approximately 38°C (100°F) and relative humidities of ambient air of approximately 50 and 25 percent, respectively. Run 6 was a repeat of run 5 to determine if problems encountered during run 5 had any significant effect on the results obtained. The test results of run 6 show no significant change in the overall drying characteristics. An extension of the drying time to 24 hours shows a gradual approach to the desired moisture content in the propellant. However, an extension of this drying time to yield an acceptable moisture in the propellant would extend the drying cycle to an unacceptable value in terms of production limitations.

Test run 7 (table 8, figure 16) showed a slightly improved slope to the drying curve over that demonstrated in run 6. However, there would be no significant improvement in the length of the drying cycle at 25 percent over that experienced at 50 percent ambient air relative humidity.

Test runs 8 and 9 (tables 9 and 10, figures 17 and 18) were conducted at ambient air relative humidities of approximately zero percent (as dry as plant air could be made using a Van Air desiccant-type dryer, zero percent on the recorder) and with drying air temperatures of 41°C (105°F) and 63°C (145°F), respectively. These tests were conducted at air-to-propellant ratios of 0.44 and 0.41 l/sec, which were slightly lower than those previously used (0.47 l/sec). This change in condition was not significant in that the purpose of the tests was to demonstrate the effect of very low humidity at the two selected temperatures in the drying of propellant.

As can be seen in figure 17, the slope of the drying curve, if extended, would yield a desired moisture level in the propellant after an extended drying cycle; whereas, propellant dried at an elevated temperature (figure 18) will reach the desired level after a much shorter cycle. Drying at this low humidity was performed for comparative purposes only, and is not considered practical for production operations.

Figure 20 shows a comparison of the 63°C (145°F) test results with an extrapolated curve for the 85 percent relative humidity test to show acceptable propellant at approximately 17.5 hours. It is believed that the 18 percent and 85 percent curves would have bracketed the 53 percent curve had the air-to-propellant ratios been at or near 1.0 and the cycles would have been shortened to approximate the 17-hour maximum

(85 percent relative humidity) observed in operations and below the 12-hour cycle at 53 percent relative humidity in the case of the 18 percent relative humidity.

An overall review of the test results shows that single-base propellant can be dried with a shorter heating cycle using thoroughly dehumidified air, but that this can only be accomplished at the present operating temperature of 63°C (145°F). Between relative humidities of 18 and 53 percent, there is no significant advantage to dehumidification.

Calculations in Appendix B show that with partial recycle of the drying air and dehumidification of the make-up air, a savings of 488.5 kg (1,077 lb) of steam can be attained during each cycle, or $0.0009 per pound of propellant. The fresh-air/recycle-air mix calculates to a 99.7 percent relative humidity for 21°C (70°F) ambient air, approximating the 85 percent drying curve in figure 11 and requiring an extended drying cycle for all cycles. Since the existing process drying cycles average only 12 hours on heat and require less steam, these savings are offset except in periods of extremely hot and humid weather.

CONCLUSIONS

The data generated in this study confirms that the drying of single-base propellant is not just a function of removing surface moisture, but is more of a function of driving the internal moisture out of the propellant granules. This phase of the drying operation requires an elevated air temperature to provide sufficient driving force to diffuse the moisture through the propellant to the surface where it can be removed. These data indicate that single-base propellant can be dried at temperatures lower than 63°C (145°F), but only if the drying time is extended.

Although the use of dehumidified air for drying single-base propellant will reduce the time required to dry the propellant, the cost of the additional energy required for regeneration of the dehumidifying agent in an adsorptive type air dryer or to compress and refrigerate the air for dehumidification offsets any savings that would be obtained from a reduced heating cycle.

Partial recycling of exhaust air from the open tank air dryer, coupled with dehumidification of make-up air for drying, will result in an extended drying cycle equivalent to that currently experienced in operations during hot, humid weather and will result in no overall savings.

Installation of an air-to-air heat exchanger between the open tank air dry exhaust and intake air will result in an annual savings of 679,433 kg (1,498,000 lb) of 377.24 kPa (40 psig) steam or $6,471 (based on RAAP 1980 steam cost data) per dry tank. This translates to an overall savings of 21.7×10^6 kg (47.9×10^6 lb) of steam and $207,000 if installed on all 32 open tank air dry units. Installed cost of each unit is estimated by the heat exchanger manufacturer at $14,250 with a payback period of 2.04 years.

RECOMMENDATION

1. No further consideration should be given to the use of dehumidified air with or without partial recycling of exhaust air for the drying of single-base propellants in the open tank air dry units.

2. The present $63^{o}C$ ($145^{o}F$) temperature of the drying air should be maintained.

3. A single modified Des Champs Laboratories, Inc. Z Duct air to air heat exchanger should be procured and installed on an open tank air dry unit. If this first unit proves effective, exchangers should be installed on the remaining 31 open tank air dry units. The funding for the initial heat exchange unit should include engineering time to work with the manufacturer to effect required safety design modifications and perform a Hazards Analysis study on the modified exchanger design.

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5. Mass Transfer Operations - Treybal, 1955

6. Chemical Engineers' Handbook - Perry, 3rd Ed. and 5th Ed.

7. Radford Army Ammunition Plant - Memorandum R. W. Dalton to E. G. Stockton - Use of Dry Air for Removal of Moisture from Large Granulated M1 Propellants, March 16, 1976

8. Radford Army Ammunition Plant - PE-432 - Methods for Energy Conservation at Army Ammunition Plants (Report in preparation)

9. Unit Operations of Chemical Engineering - McCabe and Smith, 1956

APPENDIX A

HUMID AIR AND FAN CALCULATIONS

HUMID AIR CALCULATIONS

Terms and Equations [Treybal (5) modified for altitude]

1. Relative Humidity (% RH) = $\frac{\bar{p}}{p\ H_2O}$ (100)

   $p\ H_2O$ = saturated vapor pressure of water at t°F, inches of Hg

   $\bar{p}$ = actual vapor pressure of water at t°F, inches of Hg

2. Specific Humidity (H), lb water/lb dry air

   $H = (0.622)\ \frac{\bar{p}}{B - \bar{p}}$ $\qquad \frac{\text{Mol wt water}}{\text{Mol wt air}} = \frac{18.02}{28.97} = 0.622$

   B = Barometric Pressure, inches of Hg

3. Specific Heat (C_s), Btu for mixture/lb of air - °F

   $C_s = 0.24 + 0.45\ H$

4. Specific Volume (V_H), ft^3 of mixture/lb of air

   $V_H = (0.0252 + 0.0405\ H)(t°F + 460)\ (29.92/28.02)$

5. Standard Conditions

   t°F = 70

   B = 29.92 "Hg (use 28.02" Hg to correct for RAAP altitude when calculating specific humidity and specific volume)

Table 1. Pyschometric Data for RAAP

Air, °F	Sat Vapor Press., " Hg*	% Relative Humidity 0			20			50			80			100		
		H	V_H	CS	H	V_H	CS	H	V_H	CS	H	V_H	CS	H	V_H	CS
40	0.24767	0	13.454	0.240	0.0011	13.478	0.240	0.0028	13.515	0.241	0.0044	13.549	0.242	0.0055	13.573	0.242
50	0.36240	0	13.723	0.240	0.0016	13.759	0.241	0.0040	13.812	0.242	0.0065	13.867	0.243	0.0082	13.904	0.244
53**	0.40516	0	13.806	0.240	0.0018	13.844	0.241	0.0045	13.904	0.242	0.0073	13.966	0.243	0.0091	14.006	0.244
60	0.52159	0	13.993	0.240	0.0023	14.044	0.241	0.0058	14.123	0.243	0.0094	14.204	0.244	0.0118	14.258	0.245
70	0.73915	0	14.262	0.240	0.0033	14.337	0.241	0.0083	14.452	0.244	0.0134	14.569	0.246	0.0169	14.649	0.248
80	1.0323	0	14.531	0.240	0.0046	14.639	0.242	0.0117	14.804	0.245	0.0189	14.972	0.249	0.0238	15.087	0.251
90	1.4219	0	14.800	0.240	0.0064	14.953	0.243	0.0162	15.185	0.247	0.0263	15.426	0.252	0.0333	15.592	0.255

* Perry - Chemical Engineers' Handbook (6)

** RAAP Average Annual Temperature (Historical Data)

Fan Calculation

Fan Design

Deliver 5500 SCFM at 145°F, 28.02" Hg Barometer =
(5500)(605/530)(29.92/28.02) = 6704 ACFM

1. At 53°F average temperature of suction

0% RH = (6704)(513/605)(60)/13.806 = 24,705 lb/hr dry air
50% RH = (6704)(513/605)(60)/13.904 = 24,531 lb/hr dry air
100% RH = (6704)(513/605)(60)/14.006 = 24,352 lb/hr dry air

To heat from 53°F to 145°F using 40 psig steam

0% RH = (24,705)(0.240)(92)/920 = 592.9 lb/hr steam
50% RH = (24,531)(0.242)(92)/920 = 593.6 lb/hr steam
100% RH = (24,352)(0.244)(92)/920 = 594.2 lb/hr steam

2. At 70°F average temperature of suction

0% RH = (6704)(530/605)(60)/14.262 = 24,707 lb/hr dry air
50% RH = (6704)(530/605)(60)/14.452 = 24,382 lb/hr dry air
100% RH = (6704)(530/605)(60)/14.649 = 24,054 lb/hr dry air

To heat from 70°F to 145°F using 40 psig steam

0% RH = (24,707)(0.240)(75)/920 = 483.4 lb/hr steam
50% RH = (24,382)(0.244)(75)/920 = 485.0 lb/hr steam
100% RH = (24,054)(0.248)(75)/920 = 486.3 lb/hr steam

3. At 90°F average temperature of suction

0% RH = (6704)(550/605)(60)/14.800 = 24,707 lb/hr dry air
50% RH = (6704)(550/605)(60)/15.185 = 24,082 lb/hr dry air
100% RH = (6704)(550/605)(60)/15.592 = 23,453 lb/hr dry air

To heat from 90°F to 145°F using 40 psig steam

0% RH = (24,707)(0.240)(55)/920 = 354.5 lb/hr steam
50% RH = (24,082)(0.247)(55)/920 = 355.6 lb/hr steam
100% RH = (23,453)(0.255)(55)/920 = 357.6 lb/hr steam

4. Ratio of steam/propellant (lb/lb) or (kg/kg)

a. Basis: 5200 lb propellant and 12-hour heating cycle

Ambient Air Temp, °F	Relative Humidity, % 0	50	100
53	1.37	1.37	1.37
70	1.12	1.12	1.12
90	0.82	0.82	0.83

b. Basis: 5200 lb propellant and 15-hour heating cycle

Ambient Air Temp., °F	Relative Humidity, % 0	50	100
53	1.71	1.71	1.71
70	1.39	1.40	1.40
90	1.02	1.03	1.03

5. Cost differential for extended drying cycle

Basis: Steam consumption for 15 hours versus 12 hours of drying. Steam cost based on \$4.320/1000 lb (\$0.00952/kg) from RAAP cost account average for 1980.

M6MP for 155 mm Gun 2358.72 kg/cycle (5200 lb/cycle)

Ambient Air Temp., °F	Steam Consumption Differential, kg/kg (lb/lb)	Cost Differential \$/cycle
53	0.34	7.638
70	0.27	6.065
90	0.20	4.493

For M6MP propellant at 771,120 kg/mo (1.7 x 10^6 lb) this differential at the worst condition is:

(\$7.638/cycle)(1.7 x 10^6/5200 cycles/month) = \$2497.04/month or \$29,964/year

APPENDIX B

DRYING CYCLE AND SAVINGS CALCULATIONS

DRYING CYCLE ENERGY AND SAVINGS CALCULATION

A. Basis for calculations:

1. Air flow through tank: 2596 l/s (5500 SCFM)

2. Temperature of air entering drying tank: 63°C (145°F)

3. Average ambient air temperature: 12°C (53°F)

4. Quantity of propellant being dried per tank: 2359 kg (5200 lb) dry weight

5. Specific heat of air @ 50% RH: 0.242 cal/g °C (0.242 Btu/lb °F)

6. Density of air: 1.201 kg/m^3 (0.075 lb/ft^3), std conditions

7. Standard cycle time: 54,000 s (15 hrs) total
   43,200 s (12 hrs) on heat

8. Latent heat 40 psig saturated steam: 5,111 x 10^5 cal/kg (920 Btu/lb)

B. Steam required for one cycle of propellant:

1. Current operation of 12 hours at 50% RH heated from 12°C/53°F to 63°C/145°F

   From Appendix A for calculations = 593.6 lb/hr

   Cycle steam required = (593.6)(12 hrs) = 7123 lb (3231 kg)

2. Current operation extended to 17 hours

   (593.6)(17) = 10,091 lb (4577 kg)

3. Use of Bry-Air (Model A-60-CS) Dehumidifier for total dehumidification
   a. Cycle time: 36000 s (10 hrs) from Figure 18
   b. Bry-Air dehumidified air output: 54°C (130°F) from Bry-Air Model A-60-CS
   c. Bry-Air steam to regenerate: 788 lb/hr @ 40 psig
      357 kg/hr @ 377.24 kPa
   d. Bry-Air operation: 46800 s (13 hrs)
   e. Steam required for regneration:
      (788)(13 hrs) = 10,244 lb/cycle (4647 kg/cycle)
   f. Steam to heat air from 54°C (130°F) to 63°C (145°F):
      (24705 lb/hr air)(0.240)(10 hrs)(15°F)/920 = 966.7 lb/cycle (438.5 kg)
   g. Total steam required (e + f): 11,211 lb/cycle (5085 kg)

4. Use of Bry-Air (Model A-30-AC) Dehumidifier for fresh air and partial recycle of exhaust air (figure 2)

   a. Exhaust air recycle @ 57°C (135°F) and 26% RH

      Air flow = 1416 l/s (3000 SCFM) or 1697 l/s (3596 ACFM)

      Humidity = 0.0313 kg/kg dry air (0.0313 lb/lb)

      Specific volume = 17.35 l/kg (16.675 ft^3/lb dry air)

      Specific heat = 0.254 cal/g °C (Btu/lb °F)

      Weight dry air = (3596)(60)/16.675 = 12,939 lb/hr (5869 kg/hr)

   b. Fresh air from Bry-Air @ 54°C (130°F) and 0% RH

      Air flow = 1180 l/s (2500 SCFM) or 1403 l/s (2972 ACFM)

      Specific heat = 0.240 kg/kg (lb/lb)

      Specific volume = 16.52 l/kg (15.876 ft^3/lb)

      Weight dry air = (2972)(60)/15.876 = 11,232 lb/hr (5095 kg)

   c. Air mixture heated to 63°C (145°F)

      Total weight dry air = 12,939 + 11,232 lb = 24,171 lb (10,964 kg)

      Humidity = 0.0168 kg/kg dry air (0.0168 lb/lb)

      Steam to heat recycle air from 57°C (135°F) to 63°C (145°F):

      Recycle = (12,939)(0.254)(10)/920 = 35.72 lb/hr (16.20 kg/hr)

      Dry air = (11,232)(0.240)(15)/920 = 43.95 lb/hr (19.94 kg/hr)

      Total steam = 79.67 lb/hr (36.14 kg/hr)

   d. Steam to regenerate Bry-Air = 383 lb/hr (173.72 kg/hr)

   e. Total steam/cycle:

      To heat air = (79.67)(17 hr) = 1354 lb/cycle (614.3 kg)

      to regenerate Bry-Air = (383)(20) = 7660 lb/cycle (3474.6 kg)

      Total = 9014 lb/cycle (4088.9 kg)

5. Equivalent relative humidity of recycle air mixture at ambient conditions

   a. Specific humidity = 0.0168 kg/kg dry air (0.0168 lb/lb)

   b. Vapor pressure of moisture in the mixture ($\tilde{p}$, inch Hg):

   $$\text{lb water/lb air} = (0.622)\,\frac{\tilde{p}}{28.02 \quad \tilde{p}}$$

   $$0.0168 = (0.622)\,\frac{\tilde{p}}{28.02 - \tilde{p}}$$

   $$(0.0168/0.622)(28.01 - \tilde{p}) = \tilde{p}$$

   $$0.75681 - 0.02700\,\tilde{p} = \tilde{p}$$

   $\tilde{p}$ = 0.73691 "Hg (18.7175 mm Hg)

   P_{sat} @ 21°C (70°F) = 0.73915 "Hg (18.7744 mm Hg)

   % RH = (0.73691/0.73915)(100) = 99.7%

6. Savings by use of dehumidified air (per cycle):

   a. Total dehumidification (steam consumption):

      Total steam per 10-hour drying cycle = 11,211 lb (5085 kg)

      Total steam for 17-hour extended cycle = 10,091 lb (4577 kg)

      Total dehumidification uses + 1120 lb/cycle (508 kg)

   b. Partial recycle w/dehumidification of make-up air (steam consumption):

      Recycle w/dehumidification = 9,014 lb (4,089 kg)

      Extended 17-hour cycle = 10,091 lb (4,577 kg)

      Savings = 1,077 lb (489 kg)

c. Economics of partial recycle w/dehumidification:

Steam @ \$4.320/1,000 lb

Propellant: 5200 lb/cycle

Steam saved: 1077 lb

Savings = (\$4.320)(1077/1000) = \$4.653/cycle
= \$4.653/5200 = \$0.0009/lb (\$0.002/kg)

NOTE: Normal cycle average of 12 hours on heat only 7,123 lb of steam which negates any savings, except in extremely hot and humid weather.

APPENDIX C

HAZARDS ANALYSIS STUDY OF A DEHUMIDIFIED AIR SYSTEM FOR APPLICATION IN CONVENTIONAL SINGLE-BASE PROPELLANT DRYING

HERCULES AEROSPACE DIVISION
HERCULES INCORPORATED
RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA 24141

HAZARDS ANALYSIS REPORT

AUTHOR: C. A. Parrish

SUPERVISOR: F. T. Kristoff

DATE: February 29, 1980

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HAZARDS ANALYSIS STUDY OF A DEHUMIDIFIED AIR SYSTEM FOR APPLICATION IN CONVENTIONAL SINGLE-BASE PROPELLANTS DRYING OPERATION, PE-522

Report No. 1

OBJECTIVE

To perform a total systems safety analysis in support of modification efforts to improve the efficiency of conventional open tank air drying operations for single-base propellants.

SUMMARY AND CONCLUSION

A preliminary hazards analysis performed on several concepts of a dehumidified air drying system for single-base propellants shows that the condensation-by-cooling dehumidifier is the most attractive from a safety standpoint with the adsorption and absorption-type dehumidifier next in order. The adsorption and absorption-type dehumidification concepts have potentials for compatibility and thermal initiation hazards associated with their use while no apparent hazards were identified with the condensation-by-cooling system.

SUMMARY AND CONCLUSION (continued)

From an economic standpoint, the adsorption system would be less costly to operate as the air temperature increases during the dehumidification process while it decreases in the other two systems. The overall economic aspects of the three dehumidification concepts is planned as part of Production Engineering Project PE-522.

The potential volatile solvent vapor/air mixture hazard associated with a partial recycle of exhaust air can be minimized by (a) using a closed-type heat exchanger to recover thermal energy or (b) removing the volatile solvents (and moisture) from the exhaust air by condensation.

FUTURE WORK

Further Hazard Analysis studies are planned upon concept selection and defined system design.

INTRODUCTION

The present method of drying single-base propellant is to force heated air (~130°F) through a bed of propellant granules to remove surface moisture. The air is then exhausted to the atmosphere after a single pass through the propellant resulting in a rather costly expenditure of about $3.64/1000 pounds of propellant produced. Results of laboratory testing conducted at RAAP indicate that using heated, dehumidified air with partial recycle of the exhaust air is more efficient, i.e. less costly, than the present method of drying single-base propellant.[1]

The objective of PE-522 is to design a more cost effective method of drying single-base propellant by modifying the present system to include: (a) an economical dehumidification system for the input air and (b) a partial recycle of the exhaust air, if determined to be economic. Presently, PE-522 is in the concept stage so that a qualitative preliminary hazard analysis is being performed. Further analyses including a Failure Mode and Hazardous Effects Analysis (FMHEA) and a quantitative Risk Analysis are planned once concept selection is made, design of the dehumidification system is established and drawings are available.

The total systems hazard analysis study is being performed using the Hercules Evaluation and Risk Control (HERC®) technique[2,3] which is a practical and effective method of evaluating industrial hazards. The HERC® techniques meet the system safety analysis intent of PBM OSM 385-1.

This interim report includes only a qualitative preliminary hazards analysis of several proposed dehumidification methods.

DISCUSSION

In order to reduce the amount of thermal energy being expended during single-base propellant air drying operations, it is necessary to increase the drying potential of the input air or recover a portion of the energy from the exhaust air or even a combination of the two. The drying potential of the input air can be increased

DISCUSSION (continued)

by physically removing the moisture, i.e. dehumidification. The PHA of several potential methods of dehumidification to be investigated as part of PE-522 are discussed below.

Absorption

Absorption-type dehumidifiers are those in which moisture is removed from a gas (air) stream while passing through an absorption medium of which may be either liquid or solid. As shown in Figure 1, the moist air stream enters the dehumidifier through a filter and a preheat coil where it comes into contact with the liquid absorbent by means of the contactor cells. Since some heat is generated during the moisture removal process, an automatically-controlled cooler is built into the contactor cell unit. The absorbent liquid is continuously being recycled to a regeneration unit where the original temperature and/or concentration of the solution is restored. A set of heating (or cooling) coils controls the temperature of the air stream exiting the dehumidification system.

Potential hazards identified with using an absorption-type dehumidification system to precondition the air used in the open tank air drying operation of single-base propellants are: (a) incompatibility of the liquid absorbent with the propellant and (b) thermal initiation of the propellant due to excessive air temperature. As seen in Table 1, however, some initial compatibility testing and proper temperature controls and interlocks can minimize or even eliminate the potential hazard concern.

Adsorption

Moisture is removed from a gas (air) stream in an adsorption-type dehumidifier by first condensing the moisture on the adsorbent medium surface and then drawing it into the interior by capillary attraction. The air stream temperature is increased by about 0.75°F per grain* of moisture removed per pound of air.[4/] As seen in Figure 2, the moist air is drawn in through a filter and a cycling damper where it passes through adsorbent bed A. When the adsorbent material becomes saturated and an equilibrium condition is reached, the cycling dampers switch the moist air flow to adsorbent bed B while adsorbent bed A is simultaneously regenerated.

Potential hazards identified while using an adsorption-type dehumidification system are: (a) incompatibility of the adsorbent medium with the propellant and (b) thermal initiation of the propellant due to excessive air temperature. Again, as seen in Table 1, these potential hazards can be minimized (or eliminated) by initial compatibility testing and proper controls/interlocks.

---

* 7000 grains = 1 pound

DISCUSSION (continued)

Condensation by Cooling

Moisture can be removed from an air stream by passing over a set of cooling coils having a temperature below the dew point temperature. This process, however, also reduces the air temperature and would require supplemental heating before being used in the open tank air drying operation. No potential hazards were identified while using condensation-by-cooling dehumidification system in the open tank air drying operation.

Should a partial recycle of the exhaust air be used in conjunction with a dehumidification system, a buildup of volatile solvents to within the flammable limits may be encountered inside the air drying building. This potential hazard can be minimized or even eliminated by either of two ways. The first would be to use a closed-type heat exchanger to recover the thermal energy from the exhaust air. This would prevent the dehumidified inlet air from being contaminated by volatile solvents (and moisture) as the inlet and exhaust air streams do not come into direct contact.

The second method is to remove the solvents and moisture by passing the exhaust air stream over a set of condensing coils before mixing it with the dehumidified inlet air stream. Some additional heating would be required by using this second method as the exhaust air temperature would be reduced by condensing coils.

This preliminary hazard analysis (PHA) performed on the dehumidification methods discussed in this report is qualitative and is based on concept only. As seen in Table 1, however, the analysis is useful in that it aids in establishing design criterion and controls necessary to maintain a safe and efficient operation. The hazards analysis study is on-going and will monitor the bench scale and economic feasibility studies outlined in PE-522. Qualitative Failure Mode and Hazardous Effects Analyses (FMHEA) and quantitative Risk Analyses will begin once the dehumidification method is established and preliminary drawings are available.

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1/ "Contract Scope of Work for DARCOM Project No. 5794474", January 9, 1979.

2/ "HERC® Engineering Analysis Manual, Edition I", HERC® No. 73-116 dated December, 1973.

3/ "HERC® Risk Analysis Manual, Edition I", HERC® No. 75-79 dated October, 1975.

4/ Staniar, William, Plant Engineering Handbook, 1st Ed., 1950, pp 659-671.

Table 1

Preliminary Hazards Analysis of a Dehumidified Air Drying System for Single-Base Propellant

Item Reviewed	Potential Problem Area	Recommendations for Improving Safety	Advantages	Action to be Taken
A) Absorption-type Dehumidifier or or Adsorption-type Dehumidifier	1) Incompatibility between absorbent material and the propellant.	a) Test material for compatibility before using.	Eliminates the potential hazard.	Run compatibility testing.
	2) Thermal initiation of propellant due to excessive temperature build-up during dehumidification process.	a) Install a temperature sensor in the duct with an interlock to shutdown the system and set off an alarm when a preset temperature is exceeded.	This will minimize the potential thermal initiation hazard.	Assess the control system to assure adequate safety. Review all operating and maintenane procedures for open tank air drying operations to see what changes are necessary to include a dehumidification system.
B) Partial Recycle of the Exhaust Air	1) Build-up at volatile solvents to the flammable region as a result of recycling the air.	a) Use a closed-type heat exchanger to recover thermal energy from the exhaust air.	This will prevent the inlet air and the exhaust air from coming into contact and minimizes the volatile solvent build-up.	Same as A.2.a
		or		
		b) Install cooling coils in the exhaust air line.	This will not only condense out the volatile solvents but the water also, thus dehumidifying the recycle air.	

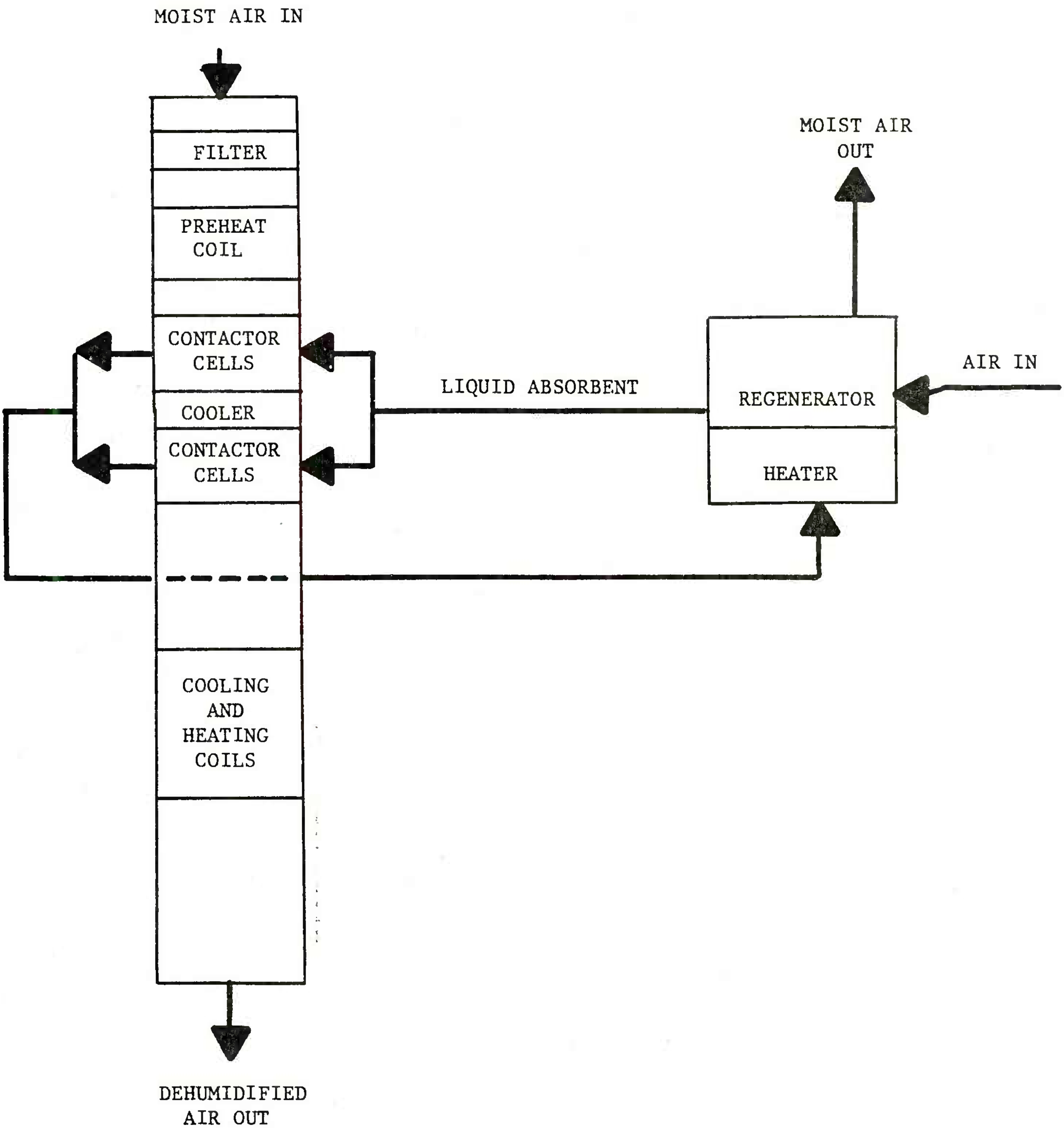

Figure 1, Typical Flow Diagram of a Liquid-Absorbent Dehumidification System

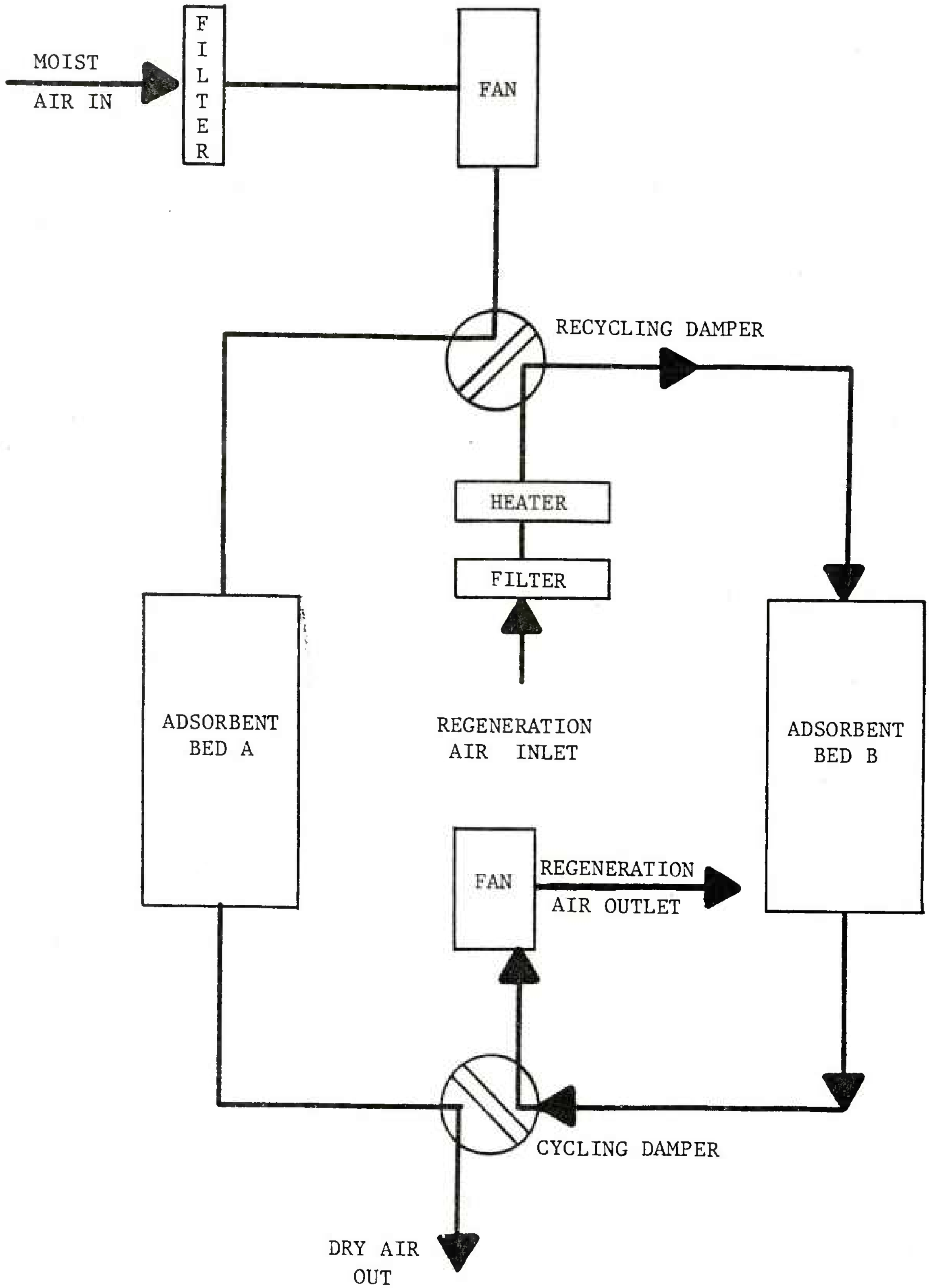

Figure 2, Typical Flow Diagram of an Adsorbent Dehumidification System

APPENDIX D

PRELIMINARY HAZARDS ANALYSIS OF A Z-DUCT HEAT EXCHANGER DESIGN FOR USE IN PROPELLANT MANUFACTURING OPERATIONS

CONTRACT NO. DAAA09-77-C-4007
RA-173 Rev. 11/77
PLANT GEN.

MEMORANDUM

25 March 1981

HA-81-M-21

Preliminary Hazards Analysis of a Z-Duct Heat Exchanger Design For Use in Propellant Manufacturing Operations

Objective

To perform a preliminary hazards analysis (PHA) and establish safety design criteria for the application of a Z-duct heat exchanger design concept in propellant/explosive environments.

Summary and Conclusions

Based on results of the preliminary hazards analysis, it is concluded that the Z-duct heat exchanger design is unsuitable for use in single-base and multi-base propellant drying operations without some modifications. The PHA performed on a typical Z-duct sample design revealed multiple potential initiation points which consists mainly of expansion/contraction friction pinch points, cracks and crevices, and rivet/screw connections. Modification of the Z-duct for application in appropriate single-base, TNT, or any propellant/explosive operation involving dry solids should be minor in terms of cost. However, for application in NG-containing operations, the modifications are expected to be major as they must meet Class A tooling standards and may not be cost effective.

Recommended safety design changes and criteria needed prior to installation of the Z-duct into any propellant or explosive manufacturing operation are presented in Table 1. The modified Z-duct design should undergo further analysis before being placed into operation.

Discussion

Application of the Z-duct heat exchanger concept design to recover and reuse a portion of latent heat exhausted to the atmosphere in conventional propellant drying operations is very attractive. A preliminary computerized economics analysis has been performed for single-base propellants and shows approximate savings of $10,000/yr/tank. The purpose of this study is: 1) to perform a qualitative preliminary hazards analysis in order to identify potential hazards that the Z-duct design may introduce into an explosive/propellant manufacturing operation and 2) to establish safety design changes and operating criteria to minimize/eliminate potential hazards found. Following are individual discussions on the Z-duct design and operation, with particular emphasis on applications in single-base and multi-base propellant drying operations.

Z-Duct Design/Operation

Evaluation of the Z-duct design was based on a sample Z-duct heat exchanger provided by the manufacturer and is characteristic of a typical Z-duct. The main heat transfer surface of the Z-duct consists of a single aluminum sheet (or any workable metal) folded many times as depicted in the top view of Figure 1. The top and bottom pieces are sealed with a refractory material and the sides and inlet/outlet ports are connected by screws and rivets. Hot exhaust air from the drying operation enters the top part of one side and exits the bottom part of the same side (shaded area). Heat from the hot air is transferred to the folded surface by convection and through the folded surface by conduction. The cold fresh air enters the bottom part of the opposite side, picks up heat through convection, and exits the top part as heated fresh air. There is no contact between the contaminated and fresh air streams which each make only a single pass through the Z-duct.

The methodology used in performing the safety assessment and review of the Z-duct design concept is a preliminary hazard analysis (PHA) and is strictly qualitative. However, the PHA is very effective from the standpoint that it is used to identify and minimize/control/eliminate potential hazards while still in the concept stage rather than in an existing process. This particular PHA emphasizes single-base application although multi-base (NG-containing) and other applications were also considered.

Single-Base Propellant Drying Application

The present design concept of the Z-duct is not readily adaptable to an explosive/propellant manufacturing operation based on typical design features reflected in the sample Z-duct. Potential initiation hazards include friction, ESD, and instability due to: 1) the expansion/contraction pinch points on the heat transfer surface, 2) the presence of cracks and crevices where propellant dust might accumulate, 3) the screw and rivet connections where dust might accumulate, and 4) the multiple pieces from which the Z-duct is constructed increases the number of bonds/grounds which must be maintained. Compatibility was also identified as a potential hazard, but test results show the refractory material to be compatible with single-base, double-base and triple-base propellants and is being mentioned only for study completeness.

Recommended design changes and additions, as presented in Table 1, include: 1) welded construction to eliminate the screws and rivets and to minimize the cracks and crevices, 2) gasketed clean-out doors on both sides of the Z-duct connected by outward, welded studs/bolts to minimize thread contamination, 3) water spray nozzles on the clean-out doors for cleaning/flushing, 4) a drain in the bottom of the unit for removing condensed solvents, and 5) flanged, gasketed inlet/outlet port connections to eliminate the use of screws during installation. Implementation of the above recommendations would not only minimize potential hazards, but it would provide ease of servicing and maintenance. In addition, operating and maintenance procedures are needed for the modified Z-duct design. The majority of the recommendations are optional features from the manufacture and thus, additional costs in accomplishing them should be minor.

Multi-Base Propellant Drying Operation

Again, installation of the Z-duct heat exchanger into multi-base propellant operations is attractive due to the amount of energy savings that might be incurred. Although the same type of potential hazards would be introduced into multi-base applications, the consequences of initiation are more severe due to the fact that NG could be present. Also, the same type of modifications are recommended to minimize/eliminate the potential hazards regardless of the materials of construction with the following additions: 1) replace the refractory material used to seal the top and bottom pieces with welds so as to avoid accumulation of NG through absorption, 2) operate the fresh air side at a higher pressure so that the fresh air will not be contaminated in the event of a leak, and 3) operate the contaminated air side above the NG dew point to avoid excessive condensation and accumulation in the Z-duct. The Z-duct must be modified in accordance with Class A tooling standards so that the modifications may be economically unfeasible.

Any modifications to the present Z-duct design should be submitted for further analysis. Should a modified Z-duct design be obtained and approved, the feasibility of additional applications on plant should be investigated.

CAP:jl

Attachments

Table 1

Potential Hazards Associated With the Use of the Z-Duct Heat Exchanger in Propellant Drying Operations

	Potential Hazards	Recommendations	Comments
I. Single-Base Propellants	A. ESD in the presence of dust and solvent-laden air due to a charge build-up from the high air flow and improper bonding/grounding.	1. Ensure that proper bonding/grounding is maintained. 2. Provide clean-out/inspection doors on both sides equipped with spray nozzles to periodically flush and clean out the Z-duct. Flushing both sides takes into account an undetected leak. 3. Provide a drain to remove all condensed solvents and water.	a. A time period for flushing and cleaning would have to be established and included in the operating procedure. b. The periodic flushing and inspection would minimize a build-up of propellant dust in the Z-duct which is a hazardous situation due to the confinement.
	B. Incompatibility of the refractory material with the propellant dust.	1. Test the refractory material for compatibility.	a. The refractory material has been tested with a single-base propellant and found to be compatible.
	C. Multiple rivet and screw connections and crevices which are potential dust accumulation points and, in time, present a potential stability hazard.	1. Replace the connections by welds to eliminate all the rivets, screws, and crevices. 2. The clean-out doors described in I.A.2 must be connected using outward welded stud/bolts with a compatible gasket material to eliminate the screws presently connecting the clean-out door. 3. Design the inlet/outlet ports so that they are flanged and gasketed connections.	a. A welded unit with clean-out and inspection doors equipped with spray nozzles for flushing and a drain to remove condensed solvents and cleaning water is needed to minimize accumulation of dust and solvents. Under the confinement of the Z-duct, accumulation of dust presents a bomb and must be avoided.

Table 1 (continued)

	Potential Hazards	Recommendations	Comments
I. Single-Base Propellants (continued)	D. Multiple pinch points that are potential initiation hazards from thermal expansion/contraction and/or excessive vibration.	1. The pinch points should be eliminated.	a. It may be difficult to eliminate some of the pinch points as they are stamped places in the metal used to separate the individual folds.
		2. Determine whether it is feasible to change the shape of the folded metal to a squared pattern rather than a pointed pattern.	b. The folds present potential accumulation and uninspectable points.
	E. Contamination of the fresh air side due to an undetected leak.	1. Operate the fresh air side at a higher pressure.	a. This would prevent contamination even in the event of a leak.
		2. Include periodic pressure testing of the heat transfer surface in the maintenance procedure.	
II. Multi-Base Propellants	A. Multiple pinch points for potential initiation of NG film during thermal expansion/contraction and vibration.	1. A clean-out/inspection door must be provided on the contaminated side and equipped with spray nozzles for periodic flushing.	a. The pinch points are inherent in the design of the Z-duct and may be difficult to eliminate as they are actually stamped places in the metal and are used to separate the individual folds.
		2. A drain should be provided to remove condensed material.	
		3. Same as I.D.2.	
	B. Multiple rivet and screw connections which are potential NG collection and initiation points.	1. The Z-duct should be modified so that all connections are replaced by welds.	a. All welds must meet Class A tooling standards.

Table 1 (continued)

	Potential Hazards	Recommendations	Comments
II. Multi-Base Propellants (continued)	C. The refractory material may tend to absorb NG which, under confinement in the Z-duct, is a very undesirable and potentially hazardous situation.	1. Replace the refractory material which is used to seal the top and bottom pieces with welds.	a. All welds must meet Class A tooling standards.
	D. Incompatibility of the refractory material with the propellant dust.	1. Test the refractory material for compatibility.	a. The refractory material has been tested with double and triple-base propellants and found to be compatible.
	E. Contamination of the fresh air side due to a leak.	1. Operate the fresh air side at a higher pressure than the contaminated air side.	a. This would minimize the potential of contaminating the fresh air stream.
		2. Include periodic pressure checks of the heat transfer surface in the maintenance procedure.	

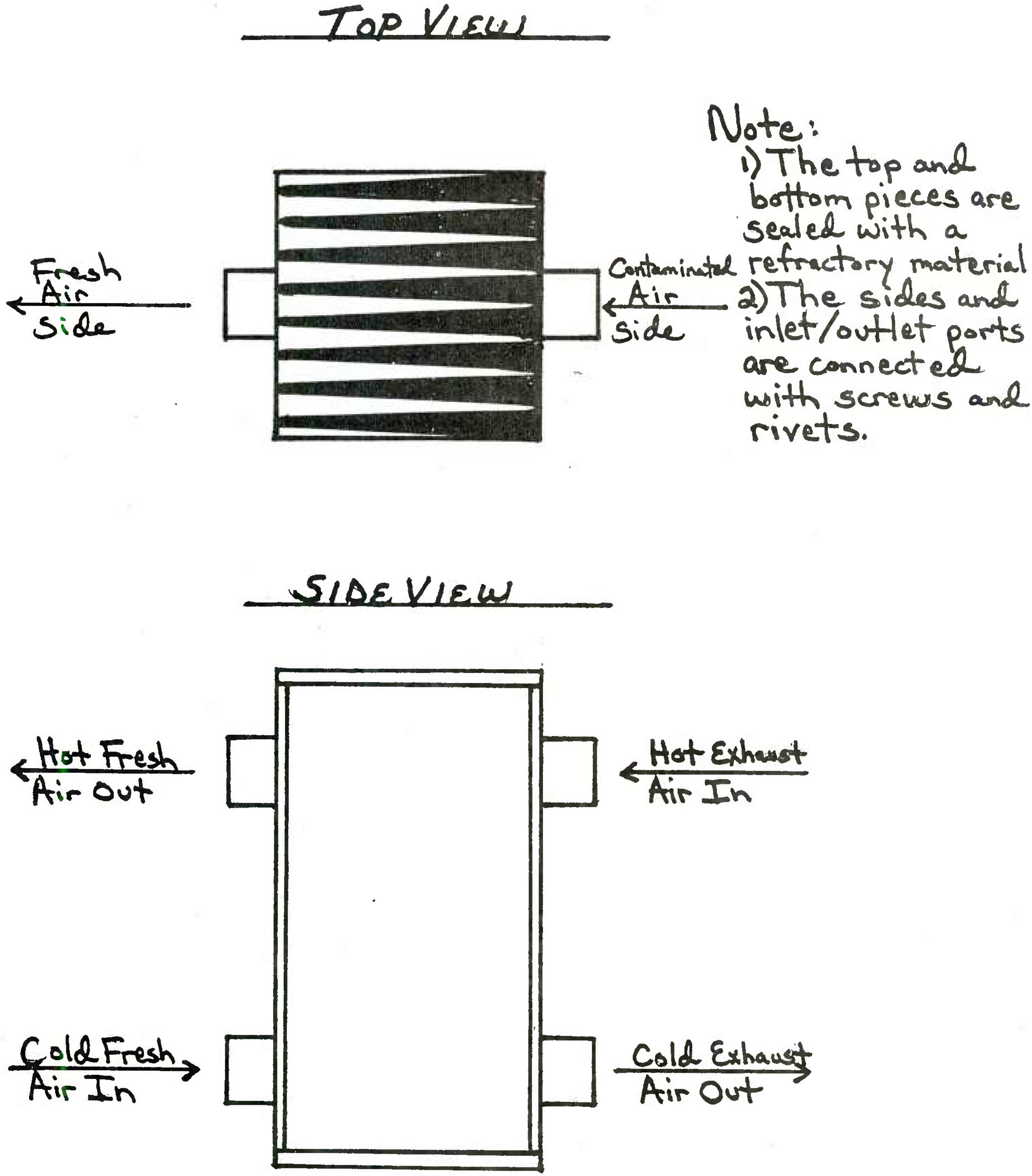

Figure 1, General Design of the Z-Duct Heat Exchanger

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