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Development of A Large-Scale Antimisting Kerosene Blender

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16. Abstract

Development of a large-scale inline antimisting kerosene (AMK) blender was undertaken to demonstrate the feasibility of inline blending on a scale that would be representative of in-service use requirements.

Inline blending was developed as means of circumventing problems that would be encountered with the use of batch-blended AMK, including: (1) unintentional degradation, (2) bulk water incompatibility, (3) filtering difficulties, and (4) shelf life. The development of the large-scale blender is traced from the laboratory-scale blender (1/2 gpm), through the continuous inline blender (10 gpm), and the intermediate blender (5 to 25 gpm). All the iterations of each unit that lead to the final configuration of the large-scale blender, which successfully performed the objective, are presented.

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EXECUTIVE SUMMARY

To reduce the post-crash fire hazard in impact-survivable aircraft accidents by using antimisting kerosene (AMK), the FAA developed a means to inline blend FM-9™ slurry into Jet A at the aircraft refueling point. This concept was pursued to circumvent problems with batch-blended AMK that had been identified by earlier work. These problems included: (1) unintentional degradation, (2) bulk water incompatibility, (3) filtering difficulties, and (4) shelf life.

The large-scale blenders, developed by the FAA, were used to fuel the B720 for the Full-Scale Transport Controlled Impact Demonstration (CID) at Edwards Air Force Base on December 1, 1984, and prior B720 flight tests on AMK. The blenders were also used to supply AMK for several of the CV880 flight degrader development tests. The large-scale blender, which was used at flow rates as high as 75 gallons per minute (gpm), was the result of development of inline blending that started with a laboratory-scale inline blender (mini-blender). The mini-blender employed a peristaltic pump to move a mixture of Jet A and FM-9 slurry through a 1/4-inch Chemineer Kenics™ static mixing tube. This blender produced discrete 1-gallon blends at a flow rate of 1/2-gallon per minute. The Jet Propulsion Laboratory (JPL) developed and built the next blender that was used by the FAA in its inline blender investigation. This unit, known as the continuous 10-GPM inline blender (10-GPM blender), produced AMK at 10 gpm and was the first blender to produce large enough quantities of inline blended AMK to allow FAA to conduct large-scale flammability tests and turbine engine runs. This inline blending capability enabled these tests to be conducted immediately after the end of a blend to evaluate AMK against a program requirement that the fuel be in specification within 15 minutes after blending. The 10-gpm unit used a 1-inch Kenics static mixing tube to disperse the FM-9 slurry in Jet A. A screw pump and a gear pump were the devices used to pump the slurry and Jet A, respectively.

Knowledge gained by using the continuous 10-GPM inline blender was used by the FAA in building a blender, known as the intermediate inline blender (5 to 25 gpm), that raised AMK blending to its next level of refinement. A major problem with the continuous 10-gpm inline blender was a ±6 percent variation in the slurry flow rate. This resulted in blends that had final concentrations which varied significantly from the 0.3-percent target concentration. A close tolerance Netzsch, Inc., Nemo™ progressive cavity, positive displacement, screw pump was used on the intermediate inline blender to pump slurry, and this pump decreased the variability in slurry flow to an acceptable level of ±1 percent.

Using the best features of the intermediate inline blender, two identical large-scale AMK blenders were built and tested by the FAA. The key features of these large-scale AMK blenders were: (1) high quality progressive cavity slurry pump (larger capacity model of pump used on intermediate blender), (2) external Jet A supply controlled by an onboard flow controller, and (3) 2-inch Inliner™ static mixing tubes. These large-scale blenders produced thousands of gallons of AMK used in turbine engine runs and AMK flight tests.

INTRODUCTION

To reduce the post-crash fire hazard in impact-survivable aircraft accidents by using antimisting kerosene (AMK), the FAA developed a prototype large-scale inline AMK blender. The blender would be used to demonstrate the feasibility of inline blending AMK at rates commensurate with in-service requirements and to fuel the B720 for flight tests and the Full-Scale Transport Controlled Impact Demonstration (CID). The blender would have to mix Jet A and FM-9™ slurry at the aircraft refueling point to circumvent problems with equilibrated AMK that had been identified early in the FAA Antimisting Fuel Program. In addition, a program requirement specified that the fuel must develop its antimisting property within 15 minutes from blend to use, to minimize impact on normal aircraft and airport operations. While, ideally, it is desirable to introduce all necessary additives in aviation turbine fuel at the refinery, the myriad of pumps, filters, and storage containers that the fuel encounters on its trip from refinery to aircraft wing tank presents some problems that make freshly blended AMK more desirable than equilibrated AMK.

These problems include:

1. Unintentional Degradation - (Restoration to Jet A properties). Laboratory characterization tests have shown that the high molecular weight polymer, FM-9, that causes the antimisting (shear-thickening) behavior of AMK, can suffer molecular damage when subjected to the shearing action of many pumps. Consequently, the level of fire protection is significantly reduced. Jet fuel is pumped many times as it moves through the complex fuel refining/distribution system before finally entering an aircraft fuel tank. A study conducted to estimate the cost of modifying the fuel handling and distribution systems at all the airports of Europe and North America to accommodate AMK, showed it would be cost prohibitive (reference 1).

2. Bulk Water Incompatibility - Exposure to bulk water, usually present in large fuel storage/delivery systems, can cause FM-9 to precipitate. In this form, the additive will readily clog filters and orifices in fuels systems (reference 2).

3. Filtering Difficulties - Filtering equilibrated AMK at moderate to high flow rates can cause large pressure drops across filters and reduce the antimisting properties of the fuel (reference 3).

4. Shelf Life - There are questions concerning what effect long-term storage might have on the antimisting properties of AMK. Although FM-9 AMK, stored in sealed containers, has a good shelf life, there is evidence that the quality of the AMK fuel may deteriorate with time when stored in vented tanks and exposed to temperature and humidity cycling.

Blending AMK at the aircraft refueling point effectively circumvents these problems associated with equilibrated AMK. Since the AMK is blended just prior to entering the aircraft, the fuel handling and filtration done prior to blending only involves Jet A, with no disruptive or expensive modifications to the present fuel storage/handling systems from refinery to airport. Exposure to bulk water in storage also involves only the Jet A and, since any bulk water can be removed by a water separator in the Jet A delivery line just prior to the blending operation, AMK water sensitivity is avoided. Furthermore, the AMK requires some time (15 minutes) to acquire its antimisting capability after the FM-9 slurry is dispersed in the Jet A by the blender. During the initial moments of this dissolution, AMK is highly resistant to unintentional degradation and, therefore, can be immediately pumped into the aircraft without a reduction in the antimisting properties of the fuel. After refueling, and before takeoff, the freshly blended AMK in the fuel tanks develops its antimisting quality, thereby assuring that high quality AMK is ready in time for the departure.

AMK BLENDING THEORY

BACKGROUND.

The design of the FAA large-scale inline blender, single stage inline mixing achieved by static mixing tubes, is based directly on developmental AMK blending research (reference 4) done by the Jet Propulsion Laboratory (JPL) under contract to the FAA. A literature search conducted by JPL revealed that the Royal Aircraft Establishment (RAE) had investigated (reference 4) blending the FM-9, in the powder form in which it is manufactured, directly into Jet A. Problems encountered with handling the very fine FM-9 powder and the extremely long dissolution time required for the powder to go into solution made blending the powder directly in Jet A impractical. Attention was then focused on blending AMK from a slurry. This product, by Imperial Chemical Industries (ICI), consisted of FM-9 powder in a glycol/amine carrier fluid. It is known commercially as Avgard™. Some successful blending of this slurry with Jet A was conducted by the RAE with the aid of a homogenizer.

AMK BLENDING REQUIREMENTS

The main function that any AMK blender must perform is to consistently produce quality AMK in a short period of time. Quality AMK, as defined by program requirements, has an acceptable level of fire protection in less than 15 minutes and also dissolves to a sufficient degree to permit efficient degradation within 30 minutes. With these goals in mind, the following blending requirements were considered in the design of the large-scale blender.

SLURRY COMPOSITION. Flammability tests conducted at the FAA Technical Center's Wing-Fuel Spillage Facility led to the conclusion (references 5 and 6) that 0.3 percent concentration, by weight, FM-9 in Jet A would produce AMK with acceptable flammability protection. This meant that when blending AMK, the slurry flow rate would be very low compared to the Jet A flow, and the need for accurately metering the slurry flow was obvious. With the carrier fluid, the volume ratio of Jet A to slurry is almost 100 to 1.

This need for accurate metering also dictated a need for a workable slurry whose flow properties would allow accurate measurement. However, the very high viscosity and poor flowing characteristic of the slurry made it very difficult to measure the flow by standard methods. Further complicating the slurry measurement was the fact that as slurry development progressed, the viscosity and pourability of the slurry often changed dramatically. These property changes lead to inaccurate slurry flow which caused incorrect FM-9 concentrations and adversely affected the resultant AMK flammability.

The slurry exhibited a distinct tendency to separate into several phases in the 5-gallon plastic pails in which it was shipped from the manufacturer. These phases usually consisted of (1) a thick, dry, coarse, almost solid layer on the bottom which could vary from 1/4 to 6 inches thick from pail to pail, (2) a milky, pastelike fluid in the middle of the pail, and (3) a clear layer of liquid on the top, perhaps 1/2 to 1 1/2 inches. This phase separation would often begin to occur in as little as 1/2 hour after mixing.

This problem made it necessary to homogenize the slurry immediately prior to blending. Recombining the separated phases was accomplished by using a Hobart V-1401™ mixing machine. Another problem that existed with early slurries was the appearance of very dense, insoluble particles of slurry in the AMK. These particles had a "fish-eye" appearance and would settle to the bottom of a container or tank and cause a buildup of a sticky gelatinous layer. A temporary solution to the "fish-eye" problem was provided by passing the homogenized slurry through a fine sieve to remove the dense insoluble slurry particles. In time, improved quality control by the slurry manufacturer eliminated the need for screening the slurry, but the separation problem persisted. However, by the time of the CID, the manufacturer of the slurry had improved slurry quality to a point where the slurry remained homogeneous as long as 6 hours after mixing.

FLOW CONTROL AND MEASUREMENT. To yield the proper final concentration when blending, it was essential to accurately control the flow of Jet A and slurry. Flow control of the Jet A was straightforward and accomplished by standard methods. Several methods were used on FAA Technical Center blenders, including: flow control by needle valves, pump speed controls, and mechanical flow controllers. Flow measurement was accomplished by turbine flow meter or by calibration through a timed catch-and-weigh method.

Flow measurement of the slurry was accomplished using a catch-and-weigh calibration procedure prior to each blend. After testing several different types of slurry pumps, the best results were obtained with accurately controlled progressive cavity, positive displacement screw pumps.

SLURRY DISPERSION. The method and location of introducing the FM-9 slurry into Jet A prior to the static mixing tube affected the quality of the AMK to a great extent. FM-9 slurry does not readily dissolve in Jet A. When the slurry is exposed to Jet A under the wrong flow conditions, or statically, it forms a sticky gelatinous substance that does not dissolve. Therefore, the slurry must be uniformly dispersed as soon as possible after introduction into the Jet A, under the proper level of turbulence.

FIRE PROTECTION AND DEGRADABILITY. As stated before, the AMK blender must consistently produce AMK that has known fire suppression (shear-thickening) qualities but which can still be degraded for combustion in the engine. As soon as the slurry is dispersed in the Jet A, it begins to dissolve. This dissolution rate determines how soon the AMK acquires its shear-thickening behavior and, therefore, provide the desired flammability quality.

To minimize the impact upon airline and airport operations, it is required that the AMK be in a usable state (fire suppressant and degradable) in less than 30 minutes. This was based on a program requirement that considered a half hour the minimum turnaround time required from engine shutdown at terminal arrival, through passenger onload and offload, baggage transfer, food service, refueling, to taxi and takeoff. The AMK must acquire the necessary properties in the time from end of refueling to push off from terminal to insure fire suppression capabilities before takeoff.

BLENDER FLOW RATE. The large-scale inline blender was developed with a design flow rate of 125 gallons per minute (gpm). While this flow rate does not approach maximum aircraft refueling rates (on the order of 500 to 700 gpm), it was the highest flow rate that could be handled at the FAA Technical Center facility where the blender development was conducted. Since the techniques used in progressing from the mini-blender to this 125-gpm rate were essentially the same, extension to the in-service fueling rates was considered technically practical. Also, since this blender was basically intended as a developmental prototype to demonstrate the concept, the 125-gpm flow rate was deemed acceptable.

IMPACT ON STANDARD AIRCRAFT REFUELING PROCEDURES. To minimize the disruption and expense that would be incurred with an airline/airport industry-wide change to the use of AMK, the large-scale inline blender was designed to be an add-on to a standard aircraft fuel truck or hydrant system. The Jet A fuel pumper trucks or hydrant line that supply the fuel to an aircraft tank would be used to supply Jet A to the blender where the FM-9 slurry is added. From the blender, the freshly blended AMK flows through hoses directly into the aircraft tanks. To demonstrate this capability, the blender was equipped with standard aircraft single-point refueling hardware on the inlet side of the blender. However, the discharge side of the blender was equipped with an overwing fueling nozzle. Over-wing hardware was chosen to avoid anticipated problems that could be encountered with the pressure and flow regulating features of a standard aircraft single-point fill valve, since the blenders were not equipped to handle large downstream pressure changes. However, future AMK blenders could easily be designed to accommodate the pressure changes that can be incurred with single-point refueling valves, by incorporating a proportional controller on the slurry pump and an automatic dump valve and waste tank to catch any improperly blended fuel.

METHODS OF BLENDING

The final design of the large-scale inline blender was based on the development of various AMK blenders used at the FAA Technical Center. In this section, each blender, and the various configurations, will be described in detail and chronological order to show all the contributions that influenced the final configuration of the large-scale blender.

MINI-BLENDER.

When the decision was made (December 1982) to demonstrate a large-scale inline blending capability in fueling the B720 for the CID, the logical first step was to develop a laboratory-scale inline blender (mini-blender). A capability of blending at a rate of 1/2 to 2 gpm would also be useful in obtaining small samples of blended AMK for analysis with a short turnaround time between samples. With a short turnaround, many samples could be evaluated quickly concerning blendability. A mini-blender, developed by JPL, using a Kenics™ static mixing tube had successfully demonstrated the feasibility of this blending method, so a similar mini-blender was set up at the FAA Technical Center for further development.

The very high viscosity and variability exhibited by many of the early slurries made metering the slurry very difficult, so the concept of a continuous flow blender yielded to a configuration that would produce discrete 1-gallon blends with a high degree of accuracy. By accurate initial weighing of both the Jet A and the slurry to be blended, the final concentration of each discrete 1-gallon blend was assured. The calculation used to determine the proper amount of slurry to be used for each blend was:

$$\frac{A(X)}{3057.3 \text{ g/gal Jet A} + (X)} = C$$

OR

$$X = \frac{(3057.3)\ (C)}{(A - C)}$$

where:

X = amount of slurry needed in grams slurry/gal of Jet A

A = percent, by weight, FM-9 in slurry

C = desired concentration FM-9, percent by weight, in Jet A

To blend 0.3 percent FM-9, for example, using slurry that was 25 percent FM-9 by weight, would require:

$$\frac{25X}{3057.3 + X} = 0.3\%$$

$$X = \frac{(3057.3)(0.3)}{(25 - 0.3)} = 37.1 \text{ g of slurry/gal of Jet A}$$

The mimi-blender shown in figure 1 had 5 main elements: (1) a fuel supply tank, (2) slurry injection port with 50 cc syringe with "Luer-Lok" tip, (3) Masterflex™ peristaltic pump, (4) 1/4 inch Chemineer/Kenics™ static mixing tube, and (5) AMK catch container.

The FAA procedure was to close the ball valve and fill the fuel supply tank with 1 gallon of Jet A. The Jet A could be measured by weight or volume with a scale or graduated cylinder, respectively. Then the syringe is placed on a scale and weighed. The scale is then set for the weight of the syringe, plus the proper amount of slurry; i.e., 37.1 g of 25 percent slurry and 0.3 percent target concentration, plus 0.5 g (which accounts for the amount of slurry that remains in the syringe after use). The filled syringe is attached to the "Luer-Lok" connection. Blending is started by turning on the pump, opening the ball valve, and applying pressure to the syringe piston. The pump moves the fuel and slurry combination at a rate of 1/2 gpm. For the 2-minute duration of a 1-gallon blend, steady pressure must be applied to the syringe. It is the operator's responsibility to maintain as steady a slurry flow as resonably possible and to insure that the syringe is emptied of all slurry sometime in the last 15 seconds of the blend. The AMK can be

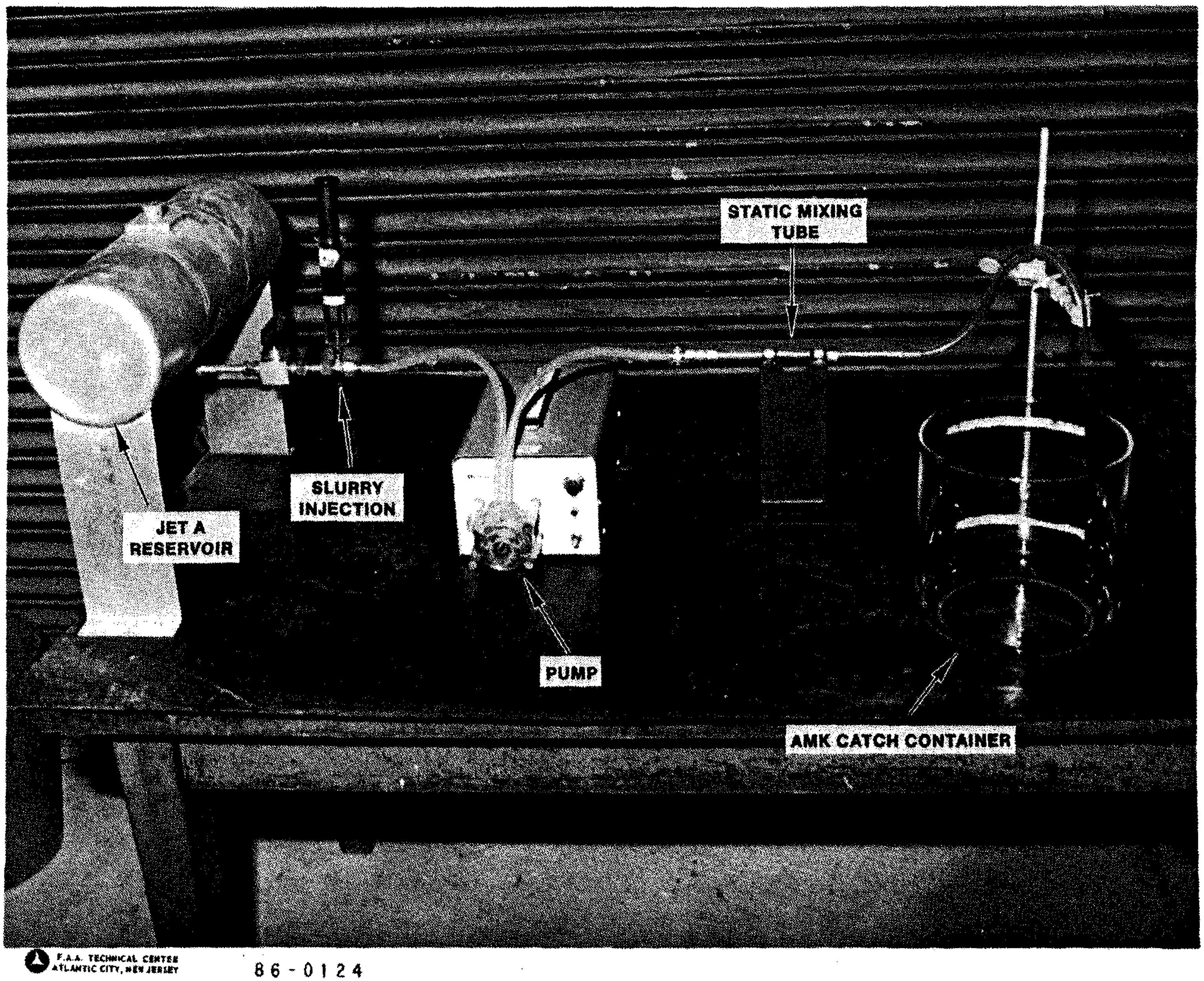

FIGURE 1. AMK MINI-BLENDER

examined in the clear glass catch container for any visual indications of undissolved slurry. Several swirls of the resultant mixture with a stirring rod or paddle, to promote the homogeneity of the mixture, are permitted to help compensate for the unsteady slurry injection.

CONTINUOUS 10-GPM INLINE BLENDER.

In February 1983, the FAA received the Continuous 10-gpm Inline AMK Blender (known as 10-GPM blender) designed and built by JPL. The design and development of this blender, up to the time of delivery to the FAA, is discussed in reference 7. The FAA used the unit in the slurry development and the refinement of the design of the large-scale blenders. The main components of the 10-gpm blender consisted of a gear pump (Teel™ Model 1P769) for the Jet A flow, a screw pump (Teel Model 1P610) for the slurry flow, and a 1-inch diameter by 12-inch long Kenics static mixing tube for the actual dispersion. JPL used a pressure gage in the slurry discharge line and a ball valve to maintain control of the slurry flow. By partially closing the ball valve in the slurry discharge line, the flow could be adjusted and the line pressure could be monitored to assure that a continuous, constant slurry flow was maintained. However, the system had an error of ±6 percent due to fluctuations in slurry flow. This fluctuation made it difficult to achieve an exact target concentration when blending. The high viscosity of the slurry made continuous manual agitation a required part of the blending process in order to prevent air bubbles from forming in the slurry feed line. The process of restricting the slurry discharge itself could also cause actual flow stoppage. This problem occurred when too many particles of slurry of varying sizes entered the restricted opening and caused an actual "log jam" as evidenced by a rapid pressure rise in the slurry discharge line. This worst case could be corrected by continuous monitoring of the pressure along with small adjustments in the position of the ball valve.

Satisfactory blends from the 10-GPM blender in terms of final concentration required careful adherence to the meticulous calibration procedure. The procedure was to calculate a target slurry flow rate in grams per minute (g/min) that would yield 0.3 percent final concentration when added to a Jet A flow held constant at 10 gpm. The target slurry flow, therefore, was dependent only on the percent loading of the polymer in the amine/glycol carrier fluid. With a target slurry flow chosen, the slurry feed system was purged for calibration. The slurry pump was run (while catching the slurry being pumped) until the slurry flow appeared to be steady and free of air bubbles. The ball valve was partially closed until the desired slurry discharge pressure was obtained, and the slurry was caught in a clean, weighed container for 1 minute. When three consecutive weighings were within ±2 grams of the target flow rate, the blender was calibrated and ready to begin blending.

A schematic of the initial configuration of the 10-GPM blender is shown in figure 2. The holding tank consists of 120 feet of 1-inch tygon tubing and 6 JPL-manufactured static mixing tubes. The holding tank was designed for use with an FM-9 slurry which did not contain amine. The amine was added separately, and JPL found it was necessary to allow 1 minute from the time of slurry introduction into the Jet A flow before the amine addition to the slurry/Jet A dispersion via the split flow paths shown in figure 2. When using the blender with standard slurries that already contained amine, it was obviously not necessary to use the amine injection leg. After gaining experience using the blender as configured in figure 2 (without amine injection), it became apparent that the blending could be simplified by eliminating the holding tank portion of the blender. This configuration, with split

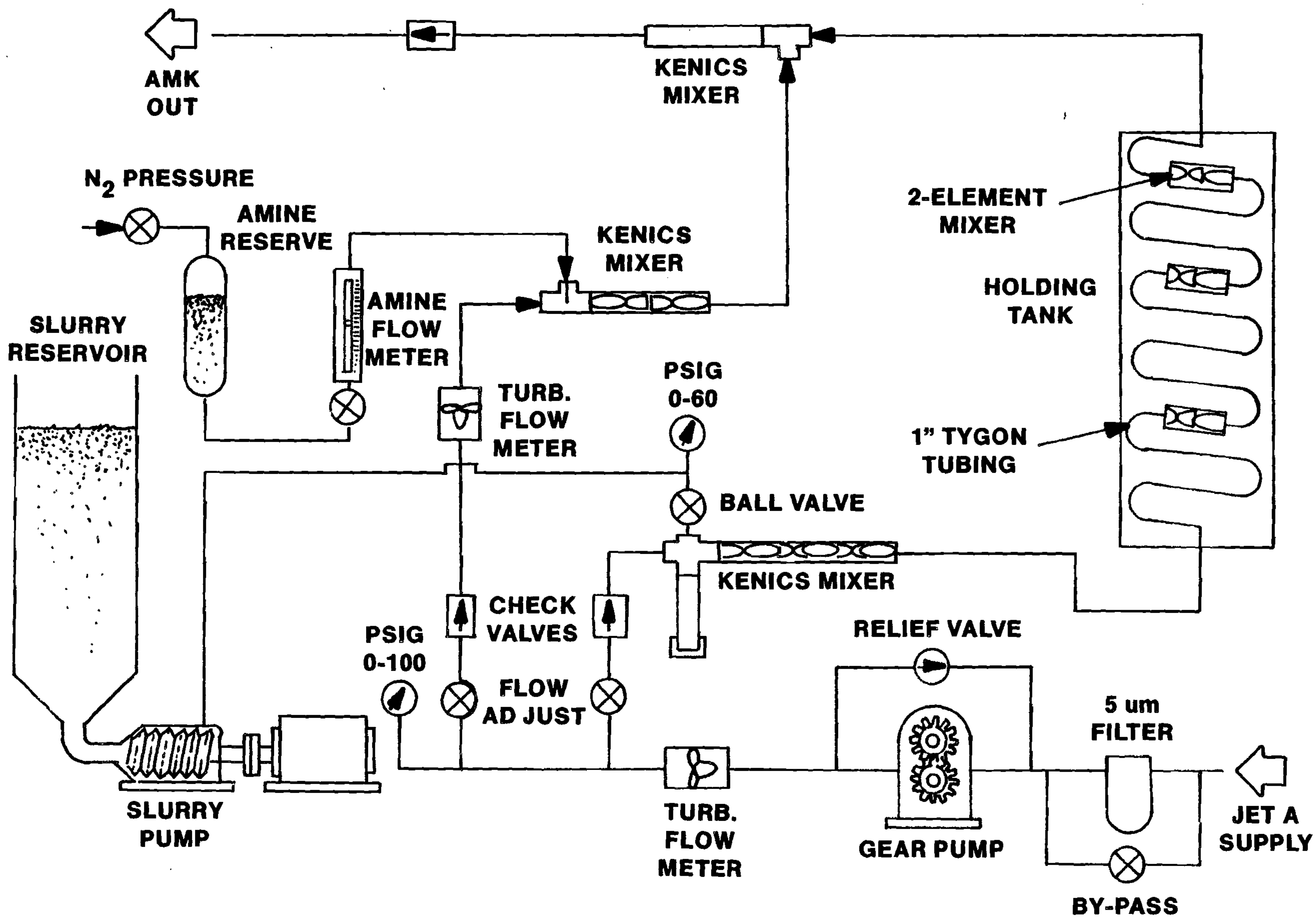

FIGURE 2. SCHEMATIC OF THE JPL CONTINUOUS 10-GPM INLINE BLENDER SYSTEM

flow and no holding tank, was used without amine injection for all blends through the rest of the year until December 1983. A remaining problem was to reduce the erratic flow characteristics of the Teel slurry pump. These efforts were never fully successful.

Another blender (discussed in the next section) that was built by the FAA, that was initially used in contractor tests at the Boeing Company in Seattle, employed a high quality, close tolerance, progressive cavity positive displacement screw pump for the slurry feed system. This pump was providing a good data base that showed much better performance in pumping slurry than with the Teel pump. A portable cart with the new slurry pump was used as the slurry feed pump in place of the Teel pump as of March 1984 and composed the final configuration of the 10-GPM blender.

INTERMEDIATE INLINE BLENDER

While blender development was going on with the 10-GPM blender, development of a larger capacity blender was undertaken. This next blender was intended for use in conjunction with the study of the environmental effects on antimisting fuels in an aircraft wing tank at the Boeing Company as detailed in reference 8. Safety regulations dictated that the blender be built to "explosion proof" standards. The blending rate was designed to be adjustable in the 5- to 25-gpm range. The main components of the blender were: (1) Jet A pump; (2) Netzsch™ slurry pump, Model 2NE15A; and (3) 2-inch Lightning™ Inliner static mixing tube. As shown in figure 3, the various components were mounted on a steel platform and that measured approximately 4 feet by 4 feet. The maximum Jet A flow rate was 6 gpm with the onboard pump. To use the blender at higher flow rates, it had to be supplied with metered pressurized Jet A. The slurry pump was controlled by a Reliance™ Electric "MinPak Plus" DC variable speed drive. The Netzsch pump is a progressive cavity screw pump with a stator section built into the pump casing. It is a very close tolerance pump (between rotor and stator) contrasted with the Teel pump used on the 10-GPM blender which had a loose fitting rotor/stator combination and a removable stator. The slurry pump used on the intermediate inline blender greatly improved the blending operation by reducing most of the uncertainty in slurry flow and by providing highly repeatable flow characteristics.

The intermediate inline blender was shipped to North Boeing Field Laboratories, Seattle, Washington, in August 1983. Boeing personnel experienced reliability problems with the Jet A pump. After several attempts to fix the pump failed, Boeing provided their own pump and turbine flow meter and continued to use the blender to support the tests they were conducting.

During the contract work, significant blending problems were experienced. These problems, which are detailed in the result section, resulted in the blender being reconfigured. A 1/2-inch Kenics static mixing tube was installed in place of the 2-inch Inliner mixing tube. Tests conducted by the FAA had shown that even with the low flow rate of 3 to 5 gpm being provided by the Boeing-supplied Jet A pump, good quality AMK could be produced using the smaller diameter mixing tube. All subsequent blending used this configuration. A total of approximately 6,000 gallons of AMK was produced over the 23 months of the Boeing contract.

Upon completion of the Boeing contract, the blender configuration was reevaluated. Since the maximum flow rate was limited by the 1/2-inch Kenics mixer, it was decided to reconfigure the unit to be a functional duplicate of the continuous 10-gpm inline blender. This work involved installing a gear pump to pump the Jet A

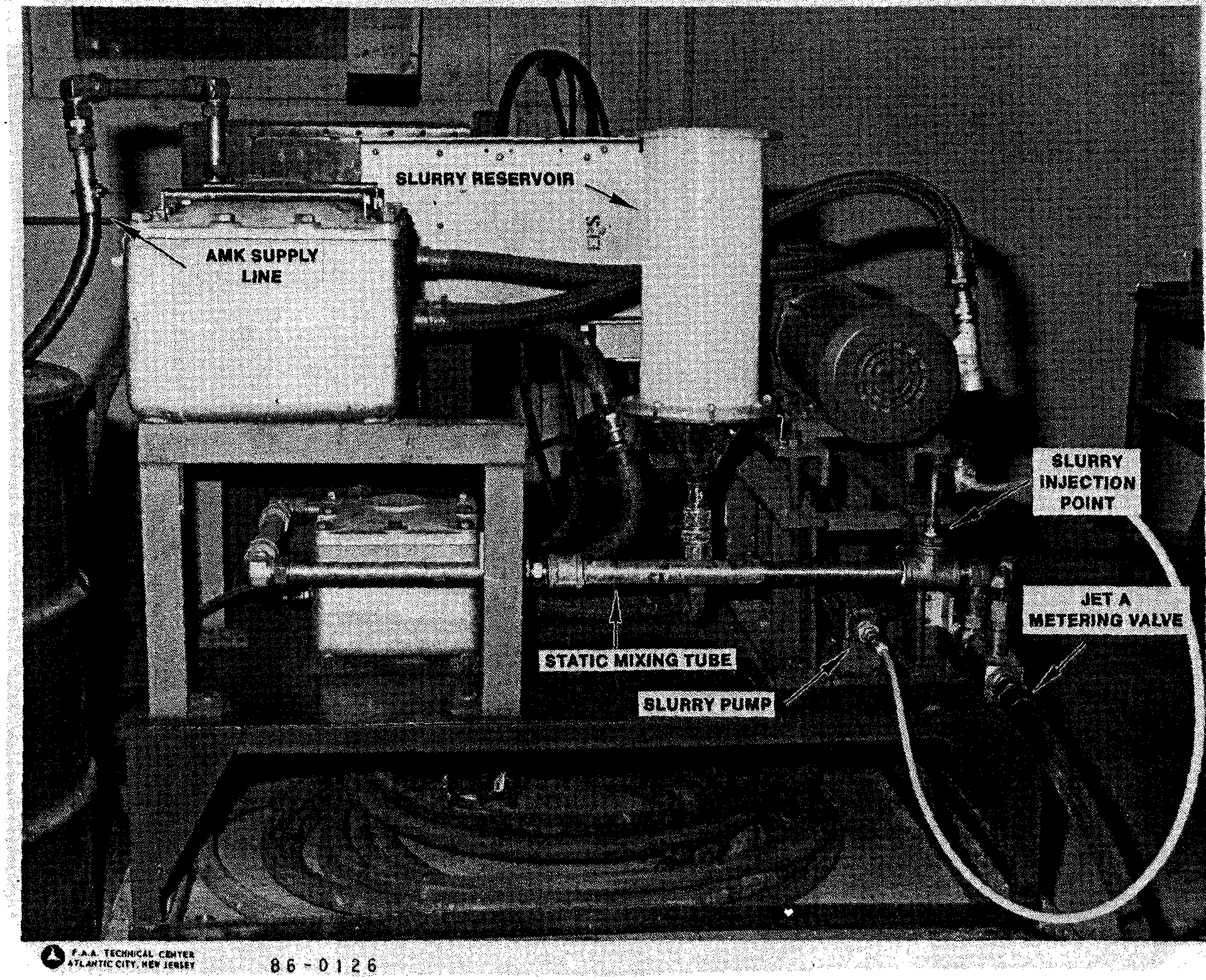

FIGURE 3. INTERMEDIATE INLINE BLENDER

and then changing the static mixing tube from a 1/2-inch to a 1-inch Kenics. As mentioned earlier, since the Netzsch slurry pump had proved to be reliable at pumping slurry, it remained. With this reconfiguration of the intermediate blender and the continuing use of a portable Netzsch pump as the slurry feed system on the 10-GPM blender, the two blenders were functionally identical. The intermediate blender, as shown in figure 3, has remained in that final configuration to the present time and is used as the working blender for ongoing tests at the FAA Technical Center.

LARGE-SCALE BLENDERS.

Two large-scale AMK blenders were designed and built by the FAA Technical Center. These blenders were intended to scale-up the demonstration of inline blending. In addition, they would then be available to fuel the B720 CID aircraft. The combination of upscaling the inline blending process and use in the CID program dictated a much larger flow rate than the 10 gpm used previously. The flow rate of 125 gpm was governed by the Technical Center fuel flow facility limit. These blenders represented the culmination of all blending experience gained from using the smaller scale blenders described earlier. As with the other blenders, the three areas of concern that had to be addressed on the large-scale blenders were (1) Jet A supply and flow control, (2) slurry supply and flow control, and (3) mixing method. The equipment choice for each area is detailed in the following paragraphs.

JET A SUPPLY AND FLOW CONTROL. In the case of each of the small-scale blenders where a maximum flow rate of 10 gpm was used, the Jet A was always supplied by an integral pump. Faced with a target flow rate of 125 gpm, it was decided that it would be impractical to have a high capacity Jet A pump integral to the blender, since capability to pump fuel already exists at airports in the form of pumper trucks or a hydrant system. Therefore, the blender was designed to use an external source for the pressurized Jet A supply. In the development work on the blender at the Technical Center, the engine test cell fuel supply system provided the Jet A source. For use in the CID Program, a refueler pumper truck would be used as the Jet A supply. Using an external means of supplying the Jet A to blender made it necessary only to have a means of controlling the Jet A flow at the blender itself. The method chosen to accomplish the control of the Jet A supply was a Kates™ Automatic Flow Rate Controller. This device controls fluid flow by maintaining a constant ΔP across an orifice. The pressure differential is sensed across a diaphragm which is rigidly connected to a valve sleeve that adjusts the opening for the fuel to pass through. Any change in the upstream or downstream pressure changes the position of the sensing diaphragm and valve ports to maintain the ΔP needed for the particular flow rate chosen. The specific Kates controller chosen was Model Number 7FA1-1, with a flow control range of from 15 to 200 gpm. The Kates controller was calibrated at the Technical Center over a range of flow rates from 20 to 60 gpm. A catch and weigh method of calibration proved the Kates to be very linear and repeatable. Calibration data for the controller can be found in appendix A.

SLURRY SUPPLY AND FLOW CONTROL. Based on the performance of the Netzsch progressive cavity pump with the smaller blenders, a Nemo pump, Model Number 2NE20A (exactly the same type pump described earlier but with a higher flow capacity) was selected for the large-scale blenders. As mentioned briefly earlier, the Netzsch Nemo progressive cavity type pump worked very well with the FM-9 slurry. Catch and weigh calibrations showed that flow rates using this pump were repeatable within a range of ±1 percent of the target flow rate. Assuming constant Jet A flow, a fluctuation of ±1 percent on slurry flow yields a variation in concentration from the target, 0.3 percent of ±0.003 percent. This degree of fluctuation combined with the Kates controller manufacturer's rating of ±1 1/2 percent yielded a maximum fluctuation from the target blending concentration of ± 2.7 percent, for a final concentration between 0.292 percent and 0.308 percent.

MIXING METHOD. From the experience gained from the blending problems encountered with the Boeing blender, the mixing device chosen to disperse the slurry into Jet A at the higher anticipated flow rate of 50 to 125 gpm was a 2-inch Lightnin™ Inliner static mixer. For optimum dispersion and homogeneity, it was determined, based on previous blending experience and consultation with the manufacturer, that two 2-inch mixers in series would be needed. A schematic of the final design and a photograph of the blender are shown in figures 4 and 5, respectively.

BLENDING PROCEDURE USED FOR THE CID.

In all the methods of blending described in the previous sections, there is no mention of monitoring slurry flow, except for the JPL method of monitoring slurry pressure, in any of the various AMK blenders. Catch and weigh calibration of the slurry flow was the method used to determine slurry flow for any particular blend. While this method yielded acceptable results as far as final percent solids was concerned, there was enough uncertainty in this method to cause real concerns about the accuracy needed for the CID blend. Approximately 12,000 gallons of AMK would be needed to fuel the B720 prior to the test, and it was apparent that the catch and weigh calibration would have to be combined with some other method of monitoring the slurry flow to insure that an AMK blend of this magnitude would be accurate.

While the need to monitor the slurry flow was evident, it was absolutely essential that the method chosen would not interfere with the actual method of blending used to date. That requirement eliminated any inline type flowmeters that might impede the slurry flow. It was decided to monitor the drop of the slurry level in the slurry hopper by installing vertical graduations that would appear as the slurry level dropped. By monitoring the elapsed time between the appearance of each graduation, any gross change in the slurry flow rate could be detected. Calculations to determine the proper increment between the graduations, based on a plan for fueling the B720 at 50 gpm per blender, showed that the elapsed time for the slurry level to pass each 2.25-inch graduation would be nominally 2 minutes. The time that was used for the CID blend was 2 minutes ±4 seconds. This 8-second spread allowed for a final concentration of 0.30 ±0.01 percent by weight.

As it turned out, this method worked quite well for the CID blend. On the day of the CID blend, ambient temperature dropped severely (over the roughly 1 1/2 hours that the blending was being conducted). FM-9 slurry viscosity is sensitive to changes in temperature, and its flow characteristics change dramatically. Since the flow of the slurry was being monitored every 2 minutes, FAA personnel were able to adjust the Jet A flow rate to maintain a desired concentration of 0.30 ±0.01 percent. As the temperature dropped, the elapsed time between graduations increased, which meant the slurry flow rate was decreasing as the temperature decreased.

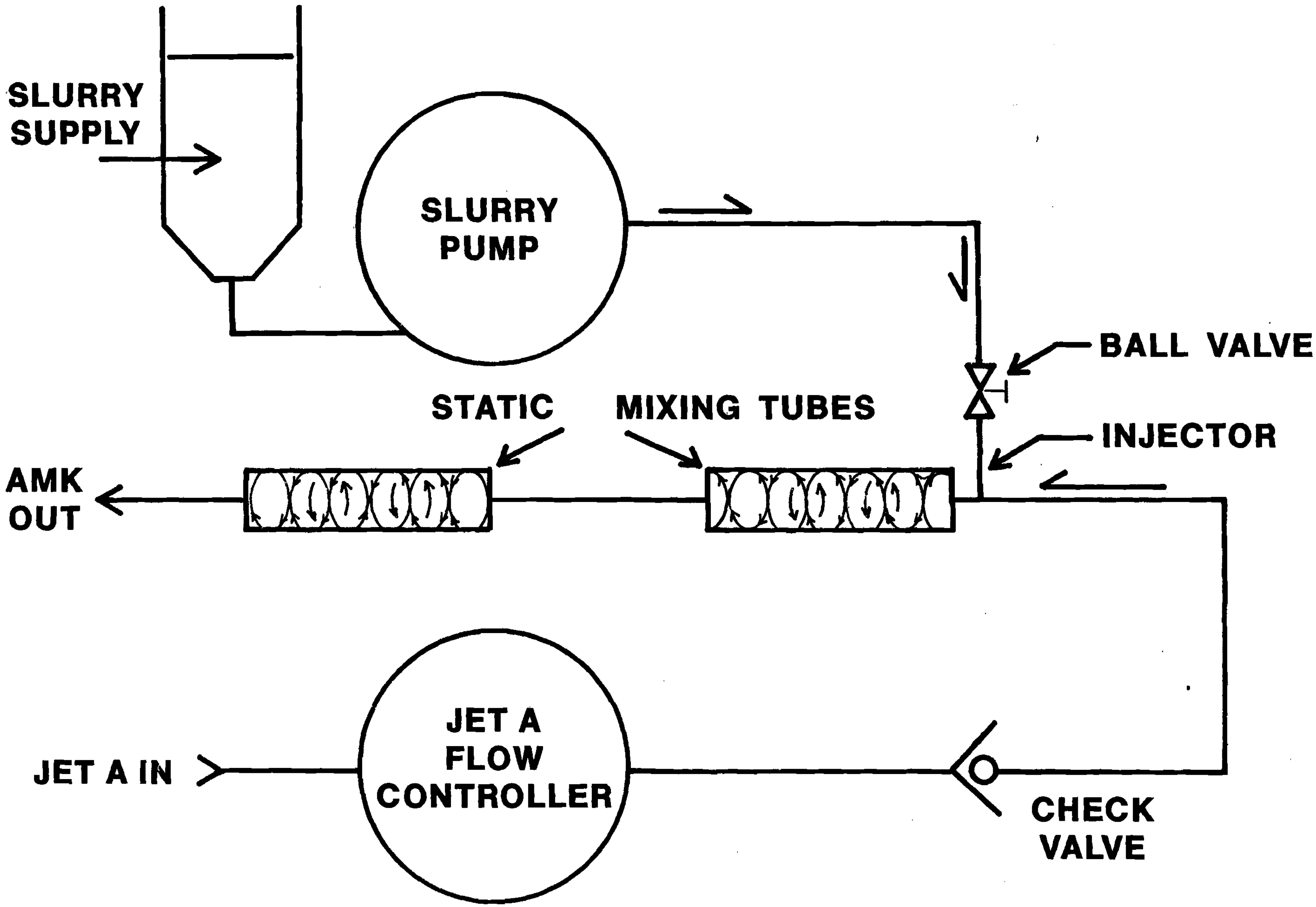

FIGURE 4. SCHEMATIC OF THE LARGE-SCALE BLENDER

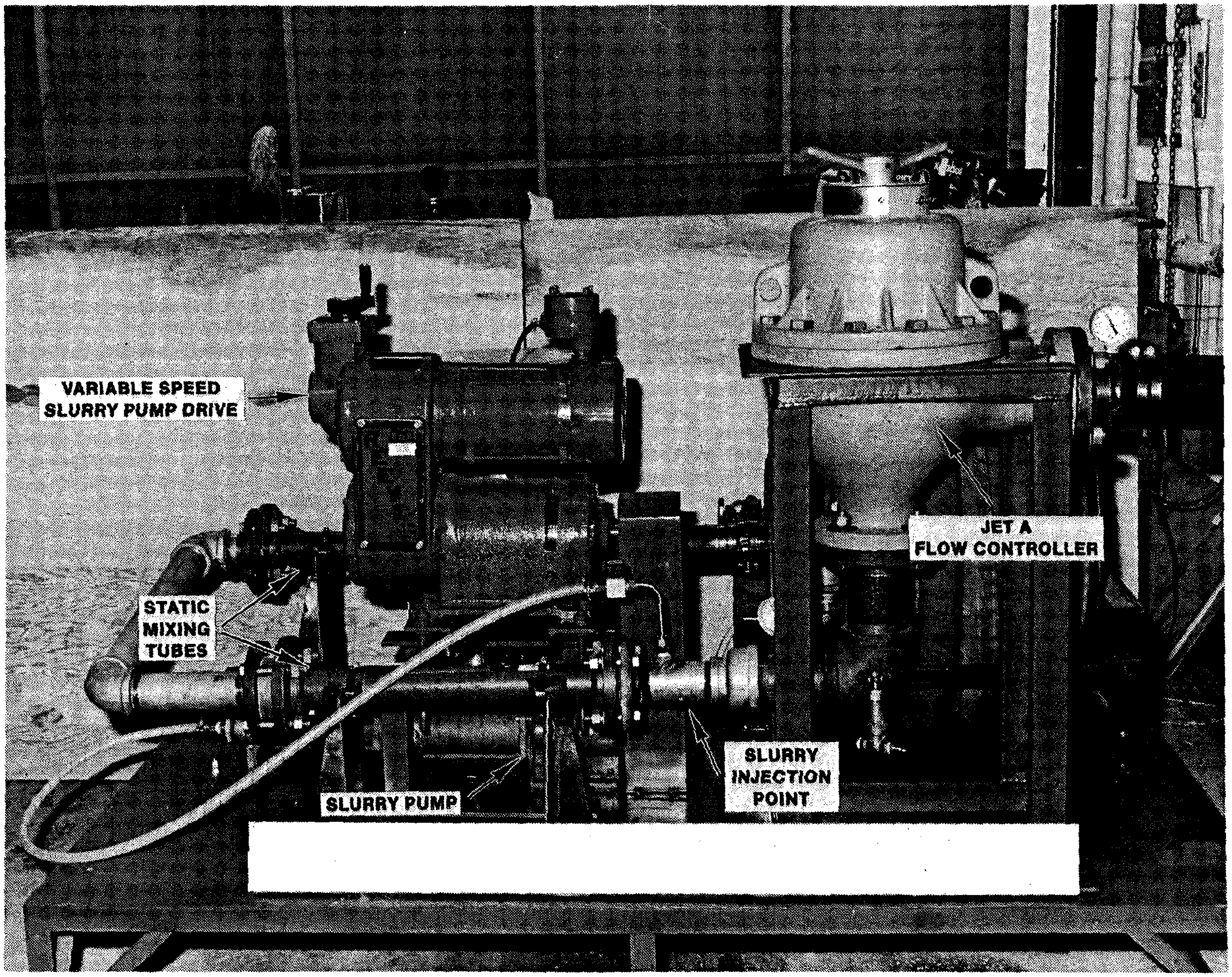

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FIGURE 5. LARGE-SCALE BLENDER

The response to the decrease in slurry flow included the following choices: (1) stop blending if the change is too great, (2) increase the slurry pump speed to the desired slurry flow rate needed to maintain the 0.3 percent concentration, or (3) decrease the Jet A flow in proper proportion to match the decreased slurry flow rate. Two blenders were operated for the CID, with a separate team of FAA personnel on each blender. As a result of the changing ambient temperature, both blender crews saw the changing elapsed times between slurry flow gradations. One team responded by changing slurry flow to maintain the 50 gpm blending rate. The other team chose to decrease Jet A flow to match the lower slurry flow rate. Both responses worked equally well and later laboratory analysis showed all AMK blended for the CID to be within specification (AMK specifications in appendix D).

RESULTS

The experience gained using each of the methods of blending described in the previous section provided the means to demonstrate the feasibility of inline blending and resulted in the successful fueling of the B720 prior to the CID. This section will provide more detail on the actual performance of each blender in terms of the quality of the fuel produced, and will further enhance the description of the large-scale blender development.

When discussing the results of using a blender, it is important to quantify the quality of the AMK produced by Jet A and FM-9 slurry. Many laboratory tests, including but not limited to those described below, have been developed to evaluate the quality of AMK. These tests are described in detail in reference 9. There are two measures of AMK quality that can be directly attributed to the actual process of blending: (1) concentration and (2) dispersion (homogeneity) of the polymer in the fuel. Quantifying the results of a blend, known as characterizing the AMK, was accomplished by the following four labortory tests.

1. Filter Ratio - A measure of the filterability of an AMK sample where the time required for a specific volume of fuel to pass through a filter is compared with the time required for the same volume of Jet A to pass through the same filter.

2. Orifice Cup - Measurement of the volume of AMK that passes through a small orifice in 30 seconds.

3. NTU - A measure of the clarity of an AMK sample expressed in National Turbidity Units as determined by a nephelometer.

4. Solids - Percent polymer in the AMK, by weight, determined by ASTM D381 (existent gum).

Test results on a blend can then be compared with FM-9 AMK specifications (appendix D).

The 0.3 percent polymer concentration requirement for use in the CID was determined by several years of research, including over 300 large-scale wing-fuel spillage flammability tests and actual flight testing, to be the optimum concentration considering flammability protection and engine fuel system compatibility. Obviously then, a prime concern in blending AMK is to insure that the target concentration is achieved. This requirement is the one that demands constant vigilance during blending, particularly regarding the difficulty that can be encountered with maintaining a constant slurry flow over a period of time.

The second quality of AMK blending that is directly related to the design and operation of the blender is the degree of dispersion that is achieved. The AMK must be a homogeneous solution, and that depends on complete uniform dispersion of the slurry into the Jet A.

Proper dispersion is mainly achieved by the design of the mixing portion of the blender, namely the static mixing tubes. The development of all the smaller scale blenders showed that static mixing tubes are a highly reliable method of achieving proper mixing, but depend on the continuous flows of the two fluids, Jet A and FM-9 slurry. Experience has shown that given the proper Jet A flow and proper slurry flow, the required dispersion will be provided. The resultant rheological properties and degree of flammability protection achieved become a function of other factors, such as the chemical composition of the slurry and the handling of the AMK after blending, once the blender has properly metered, dispersed, and mixed the two fluids.

MINI-BLENDER.

Once the mini-blender configuration and procedure were developed, it became a valuable tool for screening slurry samples for blendability. One way of immediately determining the quality of a slurry was to visually check the blended AMK for undissolved slurry. This would appear as a sticky gelatinous material that would settle to the bottom of the container. Blending efforts were always directed toward making AMK that was completely mixed in one step. The criterion established was that if any visible remnants of undissolved slurry were evident to the naked eye, the blend was determined unsuccessful.

The next step was to submit the sample to the laboratory for characterization. By performing filterability, orifice flow, and clarity tests at intervals of 15 minutes, the rate of development of the antimisting characteristic of the sample could be evaluated. Another method of evaluating mini-blender results was to blend 1 gallon and immediately test the sample for flammability protection on the Flammability Comparison Test Apparatus (FCTA), reference 10. This method consisted of picking a single FCTA data point, 16/60 (a point where high quality AMK should pass), and running a freshly blended sample repeatedly at that test point while the fuel equilibrated. At intervals of approximately 1 minute after finishing a 1-gallon blend, checking the fuel for flammability protection yielded information as shown in the following chart:

DATE: October 11, 1983
FCTA Grid Point: 16/60
Slurry Lot: 14-162

ELAPSED TIME AFTER BLEND	FCTA RESULT (P=Pass, M=Marginal, F=Fail)
4.5 minutes	F
5.0 minutes	F
6.5 minutes	M
7.5 minutes	M
8.0 minutes	M
9.0 minutes	M
10.0 minutes	P/M
11.0 minutes	P
12.0 minutes	P
13.0 minutes	P

The chart shows that the flammability protection of the fuel develops with time after dispersion occurs in the blender. In this sample, it took 11 minutes for the FM-9 slurry to dissolve enough to impart the rheological properties that inhibit mist formation and, therefore, provide flammability protection.

CONTINUOUS 10-GPM INLINE BLENDER.

FAA personnel went through an initial period of intense scrutiny of the AMK that was produced by the 10-GPM blender. The product was visually inspected by catching a sample in a clear 10-gallon glass container. Much the same as with the mini-blender, the AMK was examined to see if any particles of slurry managed to get through the mixing tubes without being dispersed enough to go into solution. From the start, this blender functioned well (with the exception of the slurry flow rate variability noted earlier), and evaluations of the AMK produced quickly jumped from 10-gallon samples for visual and laboratory characterizations to 400-gallon batches for testing on the wing-fuel spillage facility. This provided the first opportunity to evaluate, on a large scale, the equilibration of AMK in acquiring its flammability protection.

INTERMEDIATE INLINE BLENDER.

In June 1983, the intermediate blender was completed as described previously and ready for operational checkout. After the onboard slurry pump and Jet A pump were calibrated, the blender was used to blend 400 gallons of AMK, using an FM-9 slurry (Lot#JCK 13-142) which contained ethanol to improve the slurry viscosity, for wing spillage testing. The blender produced acceptable, clear AMK in this configuration, with a filter ratio of 60 and orifice cup of 1.6. During the next 2 months, the blender was checked out over the designed 5 to 25 gpm flow rate (see appendix B for operational specifics) and consistently produced quality AMK. The unit was then shipped to Boeing for use in the Wing Fuel Tank Simulator tests contract. Initially, Boeing used the blender with success and produced quality AMK for the tests. However, problems soon developed. The onboard Jet A pump malfunctioned, and after repeated repair attempts failed to correct the problem, Boeing provided an external pump to supply the Jet A to the blender. As a result of using this pump at a flow rate about half the recommended minimum of 5 gpm, inadequate mixing of the FM-9 slurry and Jet A resulted. Undissolved slurry was observed in a clear tube used on the discharge side of the blender. Boeing personnel inspected Wing Fuel Tank Simulator and discovered massive amounts of undissolved slurry. The blenders' mixing tube was removed for inspection, and the mixing blades of the tube were coated with a thick, gelatinous layer of undissolved slurry as well. Blending tests conducted by FAA using a 2-inch Inliner static mixing tube and FM-9 slurry without ethanol, like what was being used at Boeing, revealed that insufficient turbulent mixing action occurred when the flow rate dropped below 5 gpm. Under the same conditions slurry, with ethanol, went into solution quite well at 5 gpm, but the ethanol-free slurry needed more vigorous mixing action. Given the fact that the Boeing was only able to provide a maximum of about 7 gpm Jet A, it was decided to use a smaller mixing tube of the type used on the 10-GPM blender to insure sufficient turbulent mixing even at low flow rates. The blender was retrofitted with a a 1/2-inch Chemineer Kenics static mixing tube, and tests were conducted verifying that the unit would now produce quality AMK. Boeing proceeded to use the blender in this configuration for the remainder of the Wing Fuel Tank Simulator tests. Several thousand gallons of quality AMK were produced with no further difficulties (reference 10).

After the completion of the Boeing tests, the blender was shipped back to the FAA Technical Center and reevaluated. In its configuration with the 1/2-inch Kenics mixer, the maximum flow rate at which it could be operated was limited, and the decision to make this blender a functional clone of the 10-GPM blender was made.

This change was accomplished in May 1984. This final configuration is shown in figure 3, with the 1-inch by 12-inch long Kenics static mixer and the same bronze gear pump and variable speed DC drive as the 10-GPM blender. The only other change has been the use of the engine test cell fuel system at the FAA Technical Center to supply Jet A while blending. This simplified operation of the blender and required only the use of a metering valve to control the Jet A flow. This blender remains the working blender for continuing AMK investigations.

LARGE-SCALE BLENDER.

The first large-scale blender was ready for use in March 1984. A blend was made using FM-9 slurry at a rate of 50 gpm on March 9, 1984. A blend of approximately 50 gallons of AMK was produced and subjected to visual and laboratory analysis to determine whether the large-scale blender was functioning as expected. The laboratory results of this equilibrated AMK were as follows:

- Filter Ratio - 74.0
- Orifice Cup - 1.8
- NTU - 7.1
- Solids - 0.307%

Those results combined with the fact that there was no evidence of any undissolved slurry in the AMK lead to the conclusion that the large-scale blender could produce quality AMK at 50 gpm. Over the next 6 weeks (mid-March/April 1984), many AMK blends were made with the blender and repeatable results were obtained as the blender consistently produced AMK that had laboratory results similar to those above.

In an effort to see how a higher flow rate might affect the quality of the AMK produced by the blender, a blend was conducted on April 27, 1984, at the highest flow rate that could be supplied by the engine test cell fuel system at the FAA Technical Center. That flow rate was 76 gpm, and the AMK produced at that flow rate was good quality AMK as determined by the following equilibrated laboratory results:

- Filter Ratio - 73.0
- Orifice Cup - 1.9
- NTU - 12.4

Based on the successful results obtained with this first large-scale blender, plans were implemented to build a second large-scale blender so that two blenders would be available when the time arrived to fuel the Boeing 720 for the CID. This second large-scale blender was tested in August 1984 and produced fuel, blended at 50 gpm, with typically good equilibrated laboratory characterization results of:

- Filter Ratio - 76.3
- Orifice Cup - 2.0
- NTU - 6.7

Since the first large-scale blender had already been shipped (May 1984) to Edwards, California, to be used in blending AMK for B720 test flights, the second large-scale blender was used extensively between August and November of 1984 for ongoing tests conducted at the FAA Technical Center. Two of the larger blends accomplished during that time are listed in table 1.

TABLE 1. LARGE-SCALE BLENDER AMK CHARACTERIZATION EQUILIBRATED

Date	Volume	Flow Rate (Gpm)	Purpose	F.R.	O.C.	NTU
8/2/84	2200	50.0	ENGINE TEST CELL RUNS	71.8	2.0	6.8
8/28/84	2300	52.5	CV880 FLIGHT TEST TO MIAMI	61.3	1.9	10.3

By the end of October 1984, both large-scale blenders had produced thousands of gallons of quality AMK, but the most important single blend, the actual fueling of the B720 for the CID remained.

On November 29, 1984, both blenders were setup, calibrated and ready to begin the fueling operation. The blend was conducted between the hours of 3 p.m. and 6 p.m. in the afternoon. The number 1 large-scale blender was used on the left side of the aircraft and produced 6800 gallons (nominal) of AMK that filled the four tanks accessible from the left wing. The second large-scale blender was used to produce 5000 gallons that filled the three tanks accessible on the right wing of the B720. The AMK produced for this test was subjected to extensive laboratory analysis which produced the results shown in table 2, on samples taken from each tank of the B720 on the morning of the CID, December 1, 1984.

TABLE 2. CID BLEND CHARACTERIZATION

Tank	Filter Ratio	Orifice Cup	NTU	Solids (%)
NO. 1 RESERVE	71.3	1.6	8.2	.29
NO. 1 MAIN	60.4	1.8	8.6	.29
NO. 2 MAIN	69.0	1.7	8.6	.29
CENTER WING	60.8	1.6	9.2	.31
NO. 3 MAIN	69.9	1.6	9.0	.32
NO. 4 MAIN	65.8	1.6	8.4	.31
NO. 4 RESERVE	67.7	1.7	6.3	.32

The results shown above were all within the specifications for quality AMK put forth by the FAA. The production of this quality AMK, using the two large-scale blenders clearly demonstrated the feasibility of the concept of inline blending at the aircraft using overwing fueling techniques.

CONCLUSIONS

1. As demonstrated by the fueling of the B720 for the CID, inline blending FM-9™ slurry with Jet A at the aircraft refueling point would be an effective and practical method of implementing the use of AMK in commercial aviation.

2. When sized properly for a specific application, static mixing tubes are a reliable, efficient means of dispersing FM-9 slurry into fine uniform particles that will readily dissolve in Jet A.

3. Progressive cavity, positive displacement pumps are an excellent means of pumping the FM-9 slurry.

4. The methods of blending described herein are labor intensive and require the constant vigilance of the personnel doing the blending to insure that quality AMK is produced. However, there are no technical barriers preventing an engineered scale-up and automation of the system.

5. The blenders developed by the FAA produce antimisting fuels that are within specifications and provide fire protection within 30 minutes of blending, when the Jet A fuel and FM-9 slurry are of a high quality and the units are operated within design limits.

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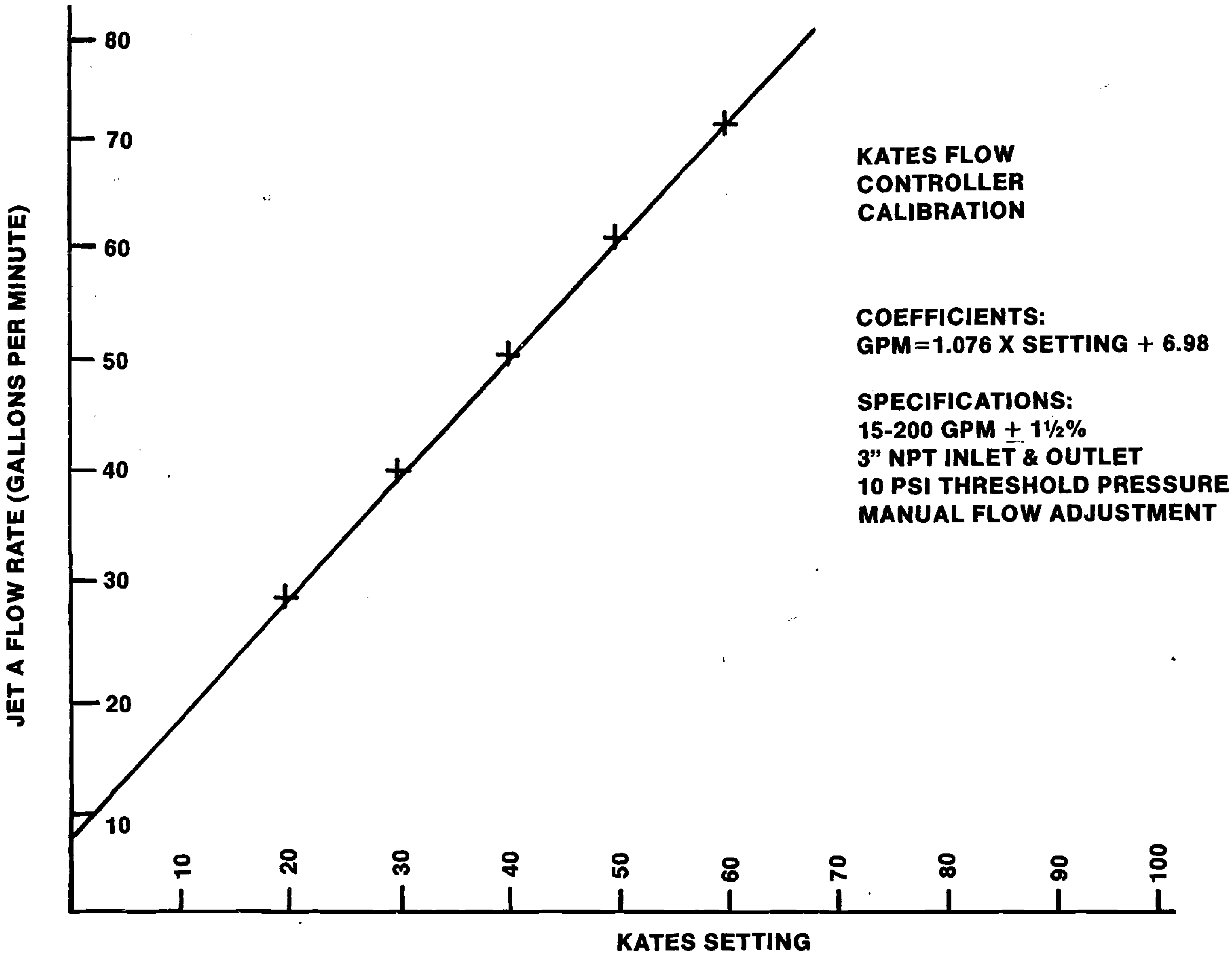
APPENDIX A

KATES FLOW CONTROLLER CALIBRATION


KATES FLOW
CONTROLLER
CALIBRATION
COEFFICIENTS:
GPM=1.076 X SETTING + 6.98
SPECIFICATIONS:
15-200 GPM ± 1½%
3" NPT INLET & OUTLET
10 PSI THRESHOLD PRESSURE
MANUAL FLOW ADJUSTMENT
JET A FLOW RATE (GALLONS PER MINUTE)
10
20
30
40
50
60
70
80
KATES SETTING
10
20
30
40
50
60
70
80
90
100

APPENDIX B

INTERMEDIATE INLINE BLENDER

DESCRIPTION AND OPERATING INSTRUCTIONS

BLENDER DESCRIPTION.

The blender consists of two controlled fluid feed systems that combine upstream of a static mixing tube. The static mixing tube relies on the fluid velocities of the combined flows to disperse and mix the two fluids into one homogeneous fluid.

The two fluid feed systems are for slurry and Jet A. The Jet A is a relatively high volume system. The slurry is a low volume feed and is metered in proportion to the Jet A, such that an 0.3 percent by weight polymer/Jet A solution results.

SLURRY FEED.

The slurry feed system consists of:

1. "Netzsch™" slurry pump, controlled by a Reliance Electric "MinPak Plus" DC variable speed drive.

2. Slurry injection tube by which the slurry is injected upstream of the mixing tube in the center of the Jet A stream. The injection is parallel to, and in the same flow direction as, the Jet A.

3. A manual shutoff valve is supplied to prevent Jet A from backing up into the slurry pump.

JET A FEED.

There are two methods of supplying Jet A to the mixing section of the blender. The first method is through an onboard pump that can accurately meter up to six gallons per minute Jet A. The second method requires an external, metered, pressurized Jet A source.

SIX-GALLON PER MINUTE (GPM) SYSTEM.

The pump is a Durco PDII diaphragm pump which is capable of up to 6 GPM flow volume control by means of a crank located on top of the pump. A digital indicator, located next to the crank reads percent output. The pump cannot be pressure fed; supply pressure must be less than discharge pressure. The supply tank should be close to the pump and on the same level as the blender.

TWENTY-FIVE GPM SYSTEM.

The slurry supply rate and mixing tube can support a blending rate up to 25 GPM. This requires an external source of Jet A. The source must be metered to an accuracy of ±0.1 GPM at a pressure between 30 and 50 psi. When using pressure feed, the fuel is input through the drain fitting downstream of the Durco pump.

BLENDER SITE REQUIREMENTS.

The contractor must supply:

1. Power: 230 volt, 36.

2. An area 15 feet by 15 feet is adequate for safe operation.

3. Fifty-five-gallon, open-top waste drum.

4. Jet A source. For high flow rates (above 6 GPM), a pressurized, metered Jet A supply.

a. Thirty psi minimum, 50 psi maximum.

b. Flow controlled and measured to ±0.1 GPM.

c. Capable of up to 25 GPM.

5. The area must have a tolerance for small spills of Jet A that may occur when making configuration changes.

6. An accurate, triple-beam gram balance, 1000 gm capability.

7. Several 1000 ml beakers.

SETUP - FIVE GPM

The contractor must supply a 1-inch AN suction hose, a 1-inch AN product hose, and a product tank.

1. Jet A Pump.

a. The Jet A pump must be suction fed. PRESSURE FEED WILL UPSET THE CHECK BALLS IN THE PUMP RESULTING IN ERRATIC FLOW.

b. Place Jet A supply tank as close to pump as possible to keep suction line short.

c. Jet A supply tank should be at the same elevation as the blender.

2. Slurry supply bucket should be placed on floor and suction tube inserted to bottom of bucket.

3. Place 55-gallon, open-top waste drum under "dump" outlet.

4. Connect 1-inch product hose to sample outlet and product tank.

PRIMING SLURRY PUMP

1. Stir slurry until uniform.

2. Place suction tube into slurry.

3. Set pump discharge tube into slurry bucket (recirculate).

5. Run pump until slurry flow is continuous.

6. Shut off pump.

7. Rinse out slurry discharge line and blow dry.

8. Reattach discharge line to pump and slurry injector.

PRIMING JET A PUMP

1. Suction line must be 1-inch or larger.

2. Suction lift must be as short as possible.

3. Place 55-gallon, open-top waste drum under dump outlet.

4. Open dump valve.

5. Set pump at 75 percent.

6. Turn pump on and let run until fuel runs out steadily.

SLURRY CALCULATION WORK SHEET

Jet A

1. Gallons per minute to be mixed. ____________

2. Multiply (1) by 6.74 lbs./gal. Jet A to get the weight. ____________

3. Multiply (2) by the final concentration to determine the polymer weight.

Example for 0.03 percent concentration:

________ lbs. Jet A X 0.003 = ________ lbs. polymer

4. Multiply (3) by 453.6 gms/lb. to convert to grams.

________ lbs. poler X 453.6 = ________ gms polymer

5. Divide (4) by percent polymer to get gms slurry.

________ gms polymer ÷ ________ percent polymer = ________ gms slurry

This number is the amount of slurry that must be pumped in ratio to the gallons Jet A desired.

Example:

5 gpm Jet A X 6.74 lbs/gal X 0.003 concentration X 453.6 gms/lb ÷ 0.25 percent

polymer = 183.4 gms slurry.

Pump Settings

From Graph:

5 GPM Jet A = 78 on digital indicator on Durco pump.

183.4 gm/min slurry = 17 on slurry pump controller.

NOTE: BECAUSE OF THE SMALL VOLUMES INVOLVED WITH THE SLURRY, THE PUMP OUTPUT SHOULD ALWAYS BE CHECKED BY THE CATCH AND WEIGH METHOD. ONCE THE ACAL PUMP OUTPUT IS DETERMINED, BACK CALCULATE TO ADJUST JET A FLOW TO MATCH.

Example

Target slurry flow rate 183.4 gms/min.

Actual Flow rate 195 gm/min.

195 gm/min. X 0.25 453.6 0.003 6.74 = 5.31 gal/min. Jet A.

New Durco pump setting = 82.

STARTUP - FIVE GPM

1. Set slurry pump to desired setting.

2. Set Jet A pump to desired setting.

3. Open dump valve.

4. Insure that sample valve is closed.

5. Insure that manual valve on slurry outlet line is closed.

6. Turn on Jet A pump and wait for flow to steady.

7. Turn on slurry pump while watching clear slurry line. As slurry reaches manual valve, OPEN IT.

8. Allow flow to continue into waste drum for 60 seconds.

9. Open sample valve.

10. Close dump valve.

11. Allow blender to run until desired amount of antimisting kerosene (AMK) is produced.

SHUTDOWN - FIVE GPM

1. Open dump valve.

2. Close sample valve.

3. Shut off slurry pump.

4. Shut off manual valve on slurry feed.

5. Run Jet A for 60 seconds.

6. Shut off Jet A pump.

7. Close dump valve. Immediately clean out slurry injection assembly.

SETUP - TWENTY-FIVE GPM

The contractor must supply a metered Jet A source (25 GPM $\pm$0.1 GPM capability at 30 to 50 psi), a 1-inch AN product hose, and a product tank.

1. Attach Jet A source to pressure feed inlet.

2. Place 55-gallon, open-top drum under dump outlet.

3. Connect product line to sample outlet and product tank.

4. Setup slurry feed as in 5 GPM configuration.

STARTUP - TWENTY-FIVE GPM

1. Set slurry pump to desired setting.
2. Open dump valve.
3. Insure that sample valve is closed.
4. Insure that manual valve in slurry feed is closed.
5. Turn on Jet A supply; adjust to desired flow rate.
6. Turn on slurry pump; open manual valve when slurry reaches it.
7. Allow to dump at least 15 seconds.
8. Open sample valve.
9. Close dump valve.
10. Allow blender to run until desired quantity of AMK is produced.

NOTE: MONITOR JET A SUPPLY AND ADJUST AS NECESSARY TO MAINTAIN ± 0.1 GPM ACCURACY.

SHUTDOWN - TWENTY-FIVE GPM

1. Open dump valve.
2. Close sample valve.
3. Shut off slurry pump.
4. Shut manual slurry valve.
5. Wait 15 seconds, then shut off Jet A supply.
6. IMMEDIATELY CLEAN OUT SLURRY INJECTION ASSEMBLY.

CLEANUP.

Immediately after blending, it is necessary to remove and clean slurry injection assembly. This is done by flushing with water, then disassembling injector/valve assembly and soaking in a solution of 75 percent xylene and 25 percent butanol. This will dissolve the gum produced when a relatively high volume of slurry encounters neat Jet A.

It is not necessary to disassemble the slurry pump each time. As long as the pump is sealed, the slurry will remain fresh. If a different composition slurry is to be used, the pump must be cleaned out to avoid contaminating the new slurry.

Water is a good solvent for virgin slurry. Any slurry that has come in contact with Jet A will form a thick gum. This can be dissolved with a solution of 75 percent xylene and 25 percent butanol.

The blender must be completely cleaned out and drained before shipment.

APPENDIX C

LARGE-SCALE BLENDER OPERATOR'S MANUAL

BLENDER DESCRIPTION

GENERAL.

Antimisting kerosene (AMK) is produced in this blending device by the controlled introduction of Avgard™ FM-9 slurry into a metered Jet A stream. A series of two static mixing tubes disperse the slurry uniformly into the fuel stream, permitting the FM-9 polymer to swell and subsequently dissolve into the Jet A.

MIXING PROCEDURE.

Blending of the FM-9 polymer into Jet A to produce AMK occurs during two distinct phases, dispersion and dissolution. During the dispersion phase, slurry containing FM-9 polymer and a glycol/amine carrier fluid is introduced into the Jet A base fuel. Static mixing tubes are used in this blending device to disperse the slurry. Other dispersion techniques (power mixers, vortex mixers, homogenizers, etc.) can also be used but have not been thoroughly evaluated to date. Static mixing tubes rely on a combination of high fluid Reynolds number and fluid residence time to thoroughly mix (disperse) diverse materials into a homogenous fluid. The degree of dispersion achieved by the static mixing tubes directly affects the polymer's ability to dissolve in the base fuel and is, therefore, an important factor contributing to final fuel quality.

The dissolution phase takes place after the polymer has been dispersed in the base fuel. Dissolution is a function of the polymer chemistry and is, therefore, affected by other factors such as ambient temperature, fuel aromatic and water content, and time.

Samples of fuel taken from the blender will exhibit changing characteristics (clarity, viscosity, etc.) for many hours after blending. Changing clarity will become immediately apparent to the blender operator.

Samples of fuel taken immediately from the blender will be cloudy, almost opaque, but will clear considerably within 15 minutes. This is a gross example of polymer dissolution.

FLUID METERING SYSTEMS

SLURRY METERING.

Because of the large Jet A to slurry volume and viscosity ratios, an extremely precise method of controlling the flow of these components must be utilized. Small changes in slurry flow will result in wider variations in FM-9 to Jet A concentration.

To insure precise flow control, a variable speed, progressive cavity pump is used to pump and meter the slurry. This pump is similar in principle to a basic screw pump but includes a special close tolerance rotor and stator that insures a nonpulsing, precisely metered flow rate up to an outlet pressure of 170 psi. This type of pump is also a low shear device which causes little or no polymer degradation.

Metered slurry is injected into the Jet A stream immediately upstream of the static mixing tube. Slurry injection is parallel to, and in the same flow direction as, the Jet A. A manual valve is used to prevent Jet A from backing up into the slurry line and pump during startup and shutdown of the blending unit. Slurry is gravity fed to the inlet of the metering pump from the stainless steel hopper.

JET A METERING.

Jet A is supplied to the blender by an external Jet A pump. This pump must be supplied by the contractor. The pressurized fuel is supplied to the inlet of the rates flow control device. This unit automatically adjusts to changes in system and inlet pressures to assure a constant preset flow rate. The flow rate is controlled by turning the set point knob on top of the controller. See attached graph for controller calibration.

BLENDER SITE REQUIREMENTS.

The following must be available at the blender site.

1. Power: 115 val 60 Hz 15 amps.

2. An area approximately 15 feet by 15 feet suitable for safe operation.

3. Jet A source.

   a. Delivery system capable of 50 to 100 gpm at 60 psi, minimum.

   b. Flow measurement to 0.5 percent.

   c. Filter/coalescer.

4. Fifty-gallon waste drum.

5. Oil absorbant material.

6. Wash water available close by.

BLENDER SET UP.

1. Carefully uncrate blender, saving all packing material.

2. Fork lift blender to blend site placing within reach of 50-foot delivery hose.

3. Connect Jet A supply.

4. Connect to 115 val.

5. Unreel 50-foot delivery hose.

6. Connect slurry delivery hose to slurry pump.

7. Attach injector to slurry delivery hose.

PRECONDITIONING OF SLURRY.

Avgard™ slurry has a definite tendency to separate into layers of vastly differing viscosities over a period of time (rate of separation is unknown). Immediately prior to use, the slurry must be thoroughly mixed to eliminate any nonuniformity. This mixing is a time-consuming operation in its present form, and adequate time must be allowed prior to blending to make sure that enough preconditioned slurry is on hand to complete the desired quantity of fuel. Care must be taken during the mixing operation to prevent dirt, water, Jet A fuel, and other hydrocarbon solvents from contacting the slurry, slurry containers, mixing equipment, hands, etc. The preconditioning procedure is as follows.

1. Wear coveralls or expendable clothing and gloves.

2. Obtain a clean, 5-gallon plastic pail.

3. Open slurry container and pour approximately one half of the material into the clean pail.

4. Manually stir and break up thick material remaining in original pail.

5. Add remaining material to clean pail, making sure all material is removed from original container. Wash and dry container and lid.

6. Mechanically or manually mix material until smooth and uniform.

7. Place screen lid on original pail.

8. Pour stirred material through screen into original container and seal container.

9. Wash and dry screen, extra pail, mixing tools, etc.

10. Slurry is now ready for use.

STARTUP PROCEDURE.

1. Priming Slurry Pump.

a. Pour slurry into stainless steel hopper, approximately 5 gallons.

b. Insure that all fittings are tight.

c. Place slurry delivery hose into waste container.

d. Start pump; set at approximately 2.5.

e. Slurry should begin flowing within 5 seconds. If not, stop pump and look for blockage. (Make sure valve at end of slurry delivery hose is OPEN.)

f. Run slurry into waste container until it appears free of contamination.

g. Place slurry delivery line into hopper for recirculation. Allow approximately 15 minutes for pump to warm up and stabilize.

h. Pump is now ready for calibration

2. Jet A Flow Rate Setting.

Determine desired Jet A flow rate. This blender is capable of operating from 50 to 100 gpm. For overwing filling, 50 gpm is recommended.

Consult attached graph to determine controller setting for desired flow rate. Set the pointer on top of controller for this flow setting.

3. Slurry Calibration Procedure

To determine the proper slurry flow rate for a desired total AMK rate, perform the following calculation.

$$F = \frac{C \times A \times B \times E}{(D-C)}$$

where:

A*= AMK flow rate, gallons per minute.

B = Specific weight of Jet A = 6.74 lbs./gallon.

C = Desired concentration = 0.30 percent = 0.003

D = Slurry polymer loading (by analysis).

E = Conversion from lbs. to grams = 453.6 gms/lb.

F = Slurry flow rate, grams per minute.

+50, 75, 100 GPM

a. Using the above formula with the exact slurry/polymer loading (obtained from the slurry manufacturer), calculate the mass slurry rate.

b. Carefully weigh plastic beaker.

c. Place slurry injector tube in hopper and open manual valve.

d. Start pump and adjust variable speed drive to a setting of 2.75.

e. Place clean plastic beaker under injector tube and catch slurry for 30 seconds. Weight slurry output.

f. Adjust slurry pump to obtain proper slurry output if number obtained in Step 3 is incorrect.

g. Repeat until slurry output is within 10 gms of calculated value.

h. Repeat at least 3 times to insure repeatability.

i. Slurry pump is now properly adjusted and ready for use.

4. Startup.

a. Remove slurry delivery hose and injector tube. Rinse with water and air dry.

b. Attach slurry delive hose to slurry pump.

c. Attach injector to slurry delivery hose.

d. Install injector (make sure manual valve is closed).

e. Place outlet nozzle into product tank (wing, drum, fuel, tank).

f. Open nozzle.

g. Start Jet A flow.

h. Wait until Jet A flow is flowing fully (2 to 3 seconds).

i. Start slurry pump. When slurry fills the slurry delivery hose, open manual valve.

j. Blender is now making AMK.

k. Add slurry to hopper as required.

5. Shutdown.

a. Close manual valve in slurry line while turning pump off.

b. Close outlet nozzle.

c. Shut off Jet A supply system.

d. Disconnect slurry delivery line at the manual valve.

e. Pump remaining slurry into original container.

6. Cleaning Procedure.

Immediately after blending, it is necessary to remove and clean the slurry injection assembly. To clean this assembly, flush hose, valve, and injector with water. Disassemble the injector and valve assembly and clean out with a test tube brush. If any gum remains in the injector, soak unit in solvent (Inhibisol) and scrub until clean. Air dry component and reassemble.

Water is the ONLY solvent to be used in the slurry system upstream of the manual valve on the slurry outlet line. Slurry supply cylinders, interconnecting tubing, and slurry pump should be flushed with clean water after each use. Operate pump while keeping slurry cylinders supplied with clean water until the output of the pump runs clear. This will do a thorough job of cleaning the internal parts of the pump, eliminating the need for disassembly.

Shut off water supply and allow pump and tubing to drain. Do not run pump dry. Seal the pump inlet and outlet by closing the slurry supply valves (beneath the slurry cylinders) and the manual valve on the slurry outlet line).

NOTE: Both the slurry system and Jet A system must be completely drained before shipment.

APPENDIX D

AMK SPECIFICATIONS

APPENDIX D AMK SPECIFICATIONS

FM-9 AMK SPCIFICATIONS

FM-9 Polymer	0.30% ± 0.02% By Weight (ASTM D 381)
Clarity*	20 NTU (Max.)
Orifice Flow Cup*	2.5 ML/30 Sec. (Max)
Filter Ratio*	35-100
Total Water	230 ppm Max. (ASTM D 1744-64)
Appearance	Uniform; No Visible Sediment
Stability	6 Months (Min.)
Jet A Base Fuel	Commercial Grade (ASTM D 1655)
	Aromatics 12 % (Min.)
	Total Water 80 ppm Max. (ASTM D 1744-64)

*30 Minutes After Blending

APPENDIX E

DISTRIBUTION

APPENDIX E

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