ALTERNATIVE DIELECTRIC COATING MEDIUM FOR ELECTRIC MOTOR FIELD COIL MANUFACTURE

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INTRODUCTION

A combination of company policy to reduce use of 33/50 chemicals, increasing production rates and implementation of the Clean Air Act Amendments (CAAA) with regard to emission limits of hazardous air pollutants (HAP) led General Electric (GE) Small Motors-Dothan to initiate a project with The University of Alabama to find a satisfactory solution to the potential problem of excess xylene air emissions from varnish curing operations. The process of interest was the coating and curing of small motor field coils with a polyester varnish using xylene as the carrier. Replacement of the current varnish with a waterborne varnish would help the plant meet environmental regulations while still expanding to take advantage of higher productivity potential in the plant. An additional benefit expected was a potential energy savings. The project was funded by the Alabama Universities-Tennessee Valley Authority Research Consortium (AUTRC) and GE, with cost-sharing by the University. GE and the University of Alabama had worked together previously on a waste reduction project in an epoxy armature-coating operation with satisfactory results.

BACKGROUND

The General Electric Company's Dothan Motor Plant produces 20,000 motors per year in a size range of 1-60 HP. The plant began production in 1975, and employs 300. In order to improve productivity and competitiveness, all manufacturing processes are being reviewed with a view towards minimizing or eliminating hazardous or other wastes and by-products while reducing costs and processing time.

Field coils are a component of motors, and the coating process for this item is under study by GE as a target for improvement. A polyester varnish coating is applied to the formed wires to stabilize the configuration and to protect the current-carrying wires in the field coil. Characteristics required in a good varnish in this application are dielectric strength, bond strength, and good thermal stability. The coating process includes coating application, forming, and convection oven curing for a total of 1.5 hours, after which the field coil enters the next manufacturing step.

Problems with the current process include energy usage, process time, safety and environmental concerns from the solvents contained in the varnish, varnish residue, and waste disposal.

ORGANIZATION

The GE plant is organized around a total quality management concept, the organization is essentially one-tiered, and the contact for the project was the quality business team leader. This organization allowed for excellent communication and action, and GE personnel reflected an open-mindedness and cooperation which helped the project move ahead. In addition, there was experience from an earlier project which eased orientation and personnel relationships. The University effort was accomplished by a research engineer and a graduate student, with oversight by Chemical Engineering faculty. The waterborne varnish supplier provided ample samples, field test equipment, extensive laboratory testing facilities, and personnel for field trials.

METHODS

A review was made of the existing production processes for coating and curing field coils using a xylene solvent polyester varnish at 50% solids. The main focus was on one of three lines used to produce field coils in the plant. Coils in this process are wound, pre-formed, dipped and cured, cooled, taped, re-dipped and cured, partially cooled, formed, and cooled. A family of waterborne varnishes was selected after discussion with GE's technical support staff, who had been reviewing candidate varnishes. These varnishes feature no or low VOC content, and a possibly shorter time and lower temperature cure cycle. Facilities were prepared for batch dipping and curing of coils. Tests were done with these varnishes in the laboratory for physical characteristics and in batch coating of coils for cure optimums, and in side-dip plant trials to determine efficacy. Final recommendations were made to GE Small Motors Management.

Existing Production Processes

Three areas of field coil production were identified, the Lanly oven/industrial main coil area, the Michigan oven/BT coil area, and the Dispatch oven/SMR field wound area. GE personnel suggested that the Lanly /industrial main coil area is the prime process area for this project, since the process can be easily duplicated in laboratory-scale tests, as the coils are separate and easy to manipulate. In this process, the prepared wound and preformed coils are hung on a conveyor which passes the coil through a bath, containing the current varnish and into an oven cure at 350°F for 90 minutes. Xylene is added to the varnish to control viscosity. Natural gas is the energy source for all three ovens. The coil then receives a nylon and fiberglass tape cover and is treated again in the same way, partially cooled, re-formed, cooled and installed in the motor frame after testing for insulation integrity. Chemical components are provided from the storeroom in five gallon pails. A waste drum, labelled hazardous, contained drippings obtained during routine cleaning and oven clean-out, which is done every week. The bath is kept at ambient temperature and the viscosity and level are checked on a routine basis. Venting of fumes to roof or side-wall is accomplished with vacuum hoods and fans.

Evaluation of Alternative Coatings

Two alternative coating materials were already selected by GE for testing. Evaluation of the varnish physical properties were critical for the success of this project. Dielectric strength is more important with this coating than the bond strength and adhesion in the armature/epoxy system studied last year, since the coil is relatively static. However, vibration can be a problem, so the final cure must be such that the coating retains integrity under thermal stress found in DC motors. Testing for physical properties and comparison to the existing varnish was carried out at the supplier's laboratory in the presence of the University project team members. This laboratory was well equipped with specialized equipment for complete testing of varnish coatings using accepted ASTM methods.

Routine physical property measurements of the varnish such as solids content and viscosity was carried out in the University's laboratory using standard procedures recommended by the supplier for solids content and GE's preferred viscosity testing using a Zahn viscometer. Bulk curing tests were attempted in aluminum cups. Measuring the hardness of the varnish cure was attempted using a penetrometer. Batch coating and curing of test coils with the new varnishes was accomplished at the University's Chemical Engineering facilities with equipment specially built for this project. Un-coated coils were supplied by GE, and varnish by the supplier. Trials were made to establish the level of coating retention, and to determine time and temperature parameters for an acceptable cure of the coil. Visual determination of coating thickness, uniformity, and completeness within the coil was attempted by electronic microscope techniques. Also, the hardness of the coil coating was estimated from penetrometer data.

Side-Dip Plant Trials

Successful laboratory tests were confirmed in side-dip plant trials. Using approximations to existing processing conditions on the Lanly Oven line, for example, coils were treated with the proposed varnish by dipping into a pail of the varnish and then putting the coils into the production line just after the normal varnish dip. In several tests, a DATAPAQ recorder (DATAPAQ, Inc., Wilmington, MA) was attached to a treatment coil allowing temperature measurement of air, coil surface, and coil interior throughout the curing cycle. Trials were also attempted on the Michigan Oven line. A DATAPAQ recorder was again utilized, but testing of the coils subsequent to curing was limited to electrical integrity only, which was acceptable, due to the fact that the coils are already mounted in housings.

RESULTS

Physical Property Tests

The initial proposed water-borne varnish selected was designated as P.D. George (PDG) 1000-Low VOC Waterborne Insulating Varnish (P.D. George Company, St. Louis, MO). Limited physical property testing for solids content (specified at 30%) and viscosity indicated variations from specification. P.D. George indicated that these problems were due to weather-related manufacturing situations, which were subsequently cleared up. Later in the project, this product was offered and tested at 34% solids, in an attempt to improve film build characteristics. Lastly, a product with slightly higher VOC content, designated as 1000-70B, with 70% solids was tested in dilutions down to 35%.

Major physical property testing of 1000-Low VOC in comparison with GE's existing xylene-based varnish was done at the supplier's laboratory facilities in St. Louis on June 13, 1994. Basically, the waterborne varnish was as good or better in tests such as dielectric strength, helical coil bond strength, pencil hardness, flexibility, and surface and volume resistivity. Film build was significantly less for the proposed varnish, which was of concern to GE.

Tests were done in the University's laboratory on the xylene-based varnish currently used by GE and the new water-based formulations for viscosity. Results are given in Table 1. Bulk testing for optimum cure cycles was attempted with poor results due to bubbling. However, samples of the current xylene-containing varnish were cured at different temperatures and subjected to a modified penetrometer test to measure degree of hardness. Conventional hardness testing equipment such as Rockwell, Brinell, and Vicker could not be used as the samples were too soft. Samples cured at 130° & 150°C were too soft to achieve results, but the data obtained for 170° and 190°C confirm an increase in hardness at higher temperatures.

The wire from a field coil was coated with both varnishes and cured and thickness measured with a micrometer. The xylene-based coating was thicker on average (two thousandths vs one thousandth). The coated wire was bent at a sharp angle and viewed under an optical microscope with polarized light at magnifications from X50 to X200. No distortion or fracture of the coating wall was observed.

Coated coils from both treatments were cross-sectioned for microscopic analysis. It was observed that the xylene-based varnish-treated coil was more compact than the water-based varnish-treated coil. Also, the xylene-base coating showed more uniformity of coating between the individual wires than did the water-base coating.

Laboratory Coating and Curing Trials

Table 2 summarizes significant results from coating and curing trials in our laboratory during the project. Parameters for varnish treatment of the field coils under

Table 1

Viscosity of Current and Proposed Varnishes

Zahn Viscometer seconds at 24°C

	XYLENE BASE	1000 - 70B	1000 - LOW VOC	1000 - LOW VOC	WATER
% SOLIDS	50	35	34	30	0
ZAHN CUP #1	188-191	133-135	50-51	32-33	30-31
ZAHN CUP #2	94-96	65-67	23-25	16-17	15-16
ZAHN CUP #3	46-48	32-34	11-12	7-8	7-8

Table 2

Summary of Coil Curing Laboratory Trials

VARNISH: IMI 9637. XYLENE BASED SOLIDS CONTENT: 50%				
SOLIDS,%	CURING TEMP., C	CURING TIME, MIN.	VARNISH USED, g	REMARKS
50	177	90	20.3	Currently in use in GE Dothan Plant

VARNISH: 1000 LOW VOC WATERBORNE SOLIDS CONTENT: 30%				
SOLIDS, %	CURING TEMP., C	CURING TIME, MIN.	VARNISH USED, g	REMARKS
30	150	60	8.2	a. First cure: very hard b. Second cure after wrapping: hard c. Film buildup: poor
30	140	60	9.0	a. First cure: medium hard b. Second cure: hard; B staging: not good c. Film buildup: poor

VARNISH: 1000 LOW VOC WATERBORNE SOLIDS CONTENT: 34%				
SOLIDS, %	CURING TEMP., C	CURING TIME, MIN.	VARNISH USED, g	REMARKS
34	121	60	13.8	a. First cure: very soft b. Not done c. Film buildup: poor
34	140	60	12.7	a. First cure: medium hard b. Second cure: very soft, pressing not effective c. Film buildup: poor
34	140	90	13.3	a. First cure: hard b. Second cure: good c. Film buildup: poor

Table 2 (Continued)

Summary of Coil Curing Laboratory Trials

VARNISH: P ED 1000 - 70B SOLIDS CONTENTS: 70%				WATERBORNE DILUTED TO DIFFERENT PERCENTAGES
SOLIDS,%	CURING TEMP., oC	CURING TIME, MIN.	VARNISH USED, g	REMARKS
50	150	70	20.1	a. First cure; very hard b. B-staging: no c. Film buildup: thick, as good as xylene varnish
40	150	75	19.2	a. First cure: very hard b. B-staging: no c. Film buildup: excellent
40	150	70	19.0	a. First cure: very hard b. B-staging: no c. Film buildup: excellent
40	150	60	18.3	a. First cure: medium hard b. B-staging: not satisfactory c. Film buildup: good
40	150	45	19.1	a. First cure: soft b. B-staging: very soft c. Film buildup: excellent
35	160	60	17.3	a. First cure: hard b. Second cure after wrapping: soft c. Film buildup: good
35	150	60	17.0	a. First cure: soft b. B-staging: no c. Film buildup: good
35	135	50	18.8	a. First cure: soft b. B-staging: no c. Film buildup: good
35	121	40	20.0	a. First cure: very soft b. B-staging: no c. Film buildup: excellent
35	110	90	17.2	a. First cure: very soft b. Second cure: very soft c. Film buildup: good
35	125	90	19.2	a. First cure: medium hard b. Second cure: soft c. Film buildup: excellent
35	140	90	19.0	a. First cure: hard b. Second cure: fair c. Film buildup:excellent
35	150	90	18.9	a. First cure: hard b. Second cure: good c. Film buildup: excellent

the current operating conditions in the GE plant are given. Coils are dipped in a 50% solids varnish containing xylene as the solvent, and are cured at 177°C for 90 minutes. Varnish retention on the coils was 20.3 grams.

Data is also given on the tests done using the PDG 1000-Low VOC waterborne varnish at 30% solids. Using the reduced curing temperature of 150°C and reduced curing time of 60 minutes as recommended by PDG, the cure was very hard, but it was found that the cure softened on reheating. Also, the varnish retention of only 8.2 grams is significantly less than the current standard, indicating insufficient film build. A rerun of this material using a curing temperature of 140°C gave a slightly softer cure. Again, the varnish retention is only 9 grams.

Tests with the 1000-Low VOC material with the solids content raised to 34% are also presented. This material was supplied by PDG after the low retention results in our lab trials and in a side-dip plant test. The results of the laboratory tests are slightly better than the 30% solids data, but still are short of the targeted retention of about 20 grams found in the control, currently used product.

Lastly, tests with PDG's 1000-70B, a 70% solids material with somewhat higher, but still acceptable, VOC content are also given. The material was diluted to a range of 35-50% solids. Curing temperatures tested ranged from 110°C to 150°C with curing times from 40 to 90 minutes, the latter time being the current standard operating time in the plant. From the results of these trials, it appears that this material, diluted for economy sake to 35% solids, retains enough viscosity to give a retention similar to that of the control xylene varnish (Table 1), and cures well at a lower temperature of 140-150°C.

Side-Dip Plant Trials

Side-dip plant trials were done on June 6 and November 30, 1994, with University and supplier personnel present.

On June 6, trials were done on both the Lanley and Michigan Oven lines, using 1000-Low VOC material at 30% solids. Six coils were treated in the Lanley Oven with the test material and were subsequently distributed three each to the University and to PDG. The DATAPAQ data collector was utilized to collect temperature and time through the oven. Lanley coils were checked for cure visually and appeared almost overcured when reformed. When cut in cross section, the lack of film build was apparent and the wires were not firmly bound in a cohesive matrix. A test was also done on the Michigan Oven line with two coils, and the DATAPAQ was again utilized, but no results could be drawn from the test due to the difficulty in evaluating the Michigan coils which are already mounted in motor housings.

Trials in November were accomplished on both lines using both 1000-Low VOC at 34% solids and 1000-70B High Solids diluted to 35% solids. The Lanley coils were deemed satisfactory using 1000-70B High Solids material diluted to 35% solids and cured at 163°C for 90 minutes. The Michigan coils are still being evaluated at the time of preparation of this report by GE and PDG, using a humidity test procedure to confirm proper coating of the NOMEX paper in the motor mount.

DISCUSSION

Tests with proposed waterborne varnishes indicate that they perform well compared to existing xylene-containing varnishes. However, in this project, problems were encountered with quality control of solids content. Apparently, supplying companies are not experienced in the problems relating to storage and shipping of water-containing formulations during winter months. Care must be exercised in acceptance of these materials in cold weather periods.

Viscosity variations from solvent-based materials to waterborne materials will also require attention. In this case, the recommended varnish at 30% solids was close to the viscosity of water, and retention of the material on a multi-wire coil of up to 1.5 inches diameter after a short ambient temperature dip was not sufficient. These results led to the supplier offering a variation up to 34% solids, but the increase was not enough to significantly improve the retention rate, as the viscosity was still significantly lower than the current varnish mix.

The supplier indicates that the solids content of 1000-Low VOC cannot be further increased. This material contains no co-solvent, only a pH adjusting chemical, dimethylethanol amine (DMEA), and has less than one pound of VOC's per gallon.

Alternatively, 1000-70B High Solids Water Borne Insulating Varnish at 70% solids and 2.63 pounds of VOC's per gallon was diluted to 35% solids and gave a satisfactory viscosity and coating retention. Use of this product would result in significantly less VOC's (2.63/2) than the existing xylene-based varnish (about 3.85 pounds per gallon VOC's), a reduction of 65%.

Potential energy savings also exist with the waterborne coatings. The supplier has indicated a curing temperature as low as 121°C for 60 minutes would give a satisfactory cure, while our tests indicate that 140-150°C are required. This is still significantly below the existing 177°C - 90 minutes condition in the Lanly Oven line.

Considering the current state of xylene emissions at the plant and anticipated production increases, a move to the 1000-70B High Solids waterborne material diluted to 35% solids appears to be a viable alternative for the GE plant for the Lanley Oven line. The data collected should also apply to the Michigan Oven and Dispatch Oven operations, but no concrete data has been collected in this study for confirmation.

CONCLUSION AND RECOMMENDATIONS

Based on the results of laboratory physical properties testing, laboratory coating and curing trials on prototype coils, and side-dip plant testing, carried out in the University's laboratories, the supplier's laboratories, and at the GE plant, replacement waterborne low VOC varnishes represent a viable alternative to xylene and other high VOC-containing insulating varnishes in field coil coating operations. Replacement of these varnishes will meet a corporate goal at GE for VOC reduction, will help the plant minimize adverse effects of the Clean Air Act Amendments (CAAA), reduce emissions reported on SARA Title III Section 313, reduce hazardous wastes, improve worker health and safety, and reduce energy consumption. GE management at the Dothan Motor Plant agree with this conclusion and expect to replace the xylene-containing varnish with the waterborne varnish as soon as practically possible, probably by mid-1995.

The results from this study can most probably be applied to other similar varnish coating manufacturing, including motor rebuilding shops.

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