Summary

Papers presented at the conference focused on areas of emphasis in coolant development work and methods of testing. The aluminum radiator and other aluminum components in engine circuits have prompted significant recent efforts to develop both appropriate coolant formulations and test methods. The more traditional cooling systems using radiators with soldered copper and brass and cast iron engines are still extensively used and efforts to improve coolant and service life in these areas continue. The heavy-duty vehicles, especially diesel engined, required particular attention and test methods continue to evolve and will become standards where consensus needs are met. These papers collectively assist in promoting our knowledge on the subject.

Starkey and Engelhardt investigated the addition of an environmentally safe organic additive to engine coolants. The objective was to reduce the effects of water hardness that produce scale deposits and buildup in high heat transfer areas. Experimental tests in a laboratory boiler proved that the additive improved heat transfer by maintaining water hardness constituents in suspension in cooling systems. Effectiveness was measured by determining the amount of scale buildup in the test boiler.

Barkley and Wiggle covered experience with service life of aluminum radiators. Satisfactory cooling systems are obviously related to components utilized. For many years, the aluminum radiator has been under development and particular concern has been expressed about corrosion durability in service. Tests performed varied from simple laboratory glassware tests to fleet trials on production radiators. More than 750 heat exchangers were examined together with the engine coolant quality, and from these results corrosion and durability predictions were made. Performance equivalent to or better than current copper and brass heat exchangers was obtained with the combination of aluminum radiators and new coolants.

Evaluation of solder bloom corrosion by a new technique that develops a corrosion index number was introduced by Park. Occasional rashes of solder bloom require intensive investigation to find solutions and Park has rationalized the investigative approach. Inspectors are provided data sheets and a series of color photographs depicting various levels of bloom attack. Miles in service and months in service are important numbers. Corrosion severity numbers are normalized using worst data at 96 560 km (60 000 miles) and 60 months, respectively. Park's solder bloom corrosion index clearly separated three different radiators in terms of their corrosion potential.

Scott introduced a new cladding alloy for vacuum brazing sheet in aluminum alloys. Sacrificial alloys to reduce or prevent tube perforation are well-known and commonly use zinc as the cladding material. In the vacuum environment, the zinc is lost and thus cladding protection is eliminated. The new clad alloy, with a nominal composition of aluminum and 0.15% tin, has a negligible vapor pressure at brazing temperatures and remains in place after this operation. The protective nature of the cladding has been determined by various laboratory tests, including electrochemical, potential, and galvanostatic testing. Aluminum automobile radiators made with this new clad material, demonstrated that the alloy has promising possibilities as a sacrificial coating for vacuum brazed aluminum radiators.

Aluminum transport corrosion wherein aluminum material is corroded from hot surfaces within the engine and deposited on heat rejecting surfaces has caused problems with losses in heat exchange efficiencies. Beard et al examined the reasons for the problem and provided a solution to its existence. Alkaline metal silicates were found to be an excellent inhibitor for this type of corrosion, but also tends to deplete during use in an engine system. The importance of stabilizing the silicate is therefore very important. Engine dynamometer tests were used for the program, including capsules with ASTM D 1384 coupons for general corrosion examinations. Coolant samples were taken during the test and analyzed for key inhibitors, pH, and any aluminum contamination. After test completion, deposits in the radiator and cylinder heads were analyzed, with deposits found to contain aluminum phosphorus and silicon. A coolant formulation that is designed to maintain silicates in solution is essential to elimination of the aluminum transport corrosion problem.

Mark and Jetten discussed the possible use of propylene glycol for automotive coolants. Equal protection against overheating and freezing can be achieved by the propylene glycol, and good cavitation is claimed. The environmental acceptability of the fluid is discussed with reference to tests on fish and biodegradability. The very bland characteristics of propylene glycol promote its' use as an automotive coolant base fluid.

Conley described an additive package for use with engine coolants that was initially brought about by the 1973 energy crisis. The U.S. Army at that time began a research project to develop a means of extending the useful life of military antifreeze MIL-A-46153. Eighteen separate formulations were tested, using ASTM Method for Corrosion Test for Engine Coolants in Glassware (D 1384). An additive package containing 29% by weight sodium metaborate, 3.0% by weight sodium mercaptobenzothiazole and 4.6% by weight potassium silicate, and 63.4% by weight water was selected. This formulation is described as MIL-A-53009. The additive package was further screened in ASTM (D 2570) simulated service test. Vehicle tests were conducted using a 3% by volume of the additive to each vehicle cooling system. Good results were obtained, even after a one-year field test, demonstrating that additive packages are practical for used coolant materials.

Current vehicle manufacturing often uses aluminum cylinder heads, water pumps, and heat exchangers, and it has been found that older engine coolant formulations that satisfactorily protected previous designs are no longer satisfactory because of excessive corrosion. Suppliers, therefore, have been required to reformulate extensively their coolant products. Vukasovich and Sullivan investigated separate and combined effects of inhibitors commonly employed in both the United States and foreign coolants. Main effects observed were concentration effects, variations in inhibitor, and pH levels on performance. Depletion effects in service were also examined, especially for stability in increasing hardness of waters used for domestic purposes. The development of the modern coolant is illustrated by this paper.

Tests methods play an important part in coolant development, and Chance et al reported on the evaluation of coolants by electrochemical methods. These authors pioneered the use of linear polarization, simulating temperature conditions at engine surfaces. The corrosion rates obtained at the heat rejecting surface was measured. This approach identified clearly the increased susceptibility of aluminum over cast iron to accelerated corrosion in the engine. Currently, the procedure is used as a screening tool for the development of inhibitors. Excellent correlations were found between electrochemical and gravimetric measurements, using a specially designed cell for the purpose. Total damage effects were investigated using anodic polarization and constant potential tests. Results indicated that cavitation-type damage may be evaluated by the electrochemical method, and that in aluminum at least, a major part of the total damage is corrosive in nature. The pitting corrosion of brass in various inhibitors was investigated by electrochemical techniques which were found to assist in inhibitor selection.

Beal introduced a dynamic test for soldered joints in a coolant environment that allows for the effect of stress and cyclic operation on the corrosion characteristics of joints in service. The test method should be used in conjunction with ASTM D-1384 glassware tests to evaluate different solder alloy materials. On the basis of selection of a particular solder alloy, this same test can be used to evaluate the corrosion resistance obtained with different coolant formulations. Solder bloom was found to increase in engine coolant at radiator operating temperatures in the presence of applied stresses under static or dynamic conditions.

Heavy-duty diesel cooling system requirements were comprehensively covered by Hudgens and Hercamp. Diesel engine manufacturers and users of heavy-duty vehicles have particular requirements and problems that need to be addressed. Supplemental coolant additives are utilized to maintain the protective features of coolants essential for wet liner operations. High mileages, of up to 24 140 km (15 000 miles) per month, rapidly deplete some of the constituents of inhibitor packages. Hudgens has demonstrated that the supplemental coolant additive approach can avoid problems arising from these depletions. The paper is provocative in places and recommends the development of additional ASTM standards that will allow better evaluation of the complex blends of chemicals which may have up to ten components used as inhibitor packages in diesel engine cooling systems. The shortcomings of current testing approaches are highlighted with some emphasis on compatibility problems which can be critical in the additive package system. Several areas of future work are recommended in glassware tests: effects of stress, refinement of electrochemical testing, and in the coolant compatability testing requirements. Anyone involved in heavy-duty diesel service will benefit from this study.

Liebold and Starke examined European test methods for automotive coolants covering their experiences with new cavitation and corrosion tests. The Forschungsvereinigung für Verbrennungskraftmaschinen (FVV) test was published in 1977 and is discussed in the paper. Coolant samples in water are tested in contact with materials removed from the engine system. A second step requires an aged antifreeze or coolant to be tested and compared to the original results. In practice, good correlation was not found with this approach, and a second test was developed by Motor-Turbinen Union (MTU). A special cavitation unit with a mechanical actuator was developed. This test equipment is installed in the general circulation system of the FVV test. More predictive results were obtained with this newer test procedure.

Billy Oakes presented a paper on observations he had made on aluminum water pump cavitation tests. Many illustrations were used to demonstrate the clear effect of different engine coolant formulation on the performance of the aluminum water pumps. Two tests were discussed, one of which is covered in ASTM Test Method for Cavitation Erosion-Corrosion Characteristics of Aluminum Pumps with Engine Coolants (D 2809), and the second test is a standard Ford laboratory test method BL-3-2. Test rig construction was found to affect results. Some coolants allow cavitation damage at low concentrations of coolants specified in the test, but perform satisfactorily when tested at concentrations recommended by coolant suppliers. Care in setting up strict direct comparisons was recommended to insure validity of results obtained.

Wiggle et al, at Ford, have looked at their own cavitation-erosion test for aluminum water pumps that uses a 15% coolant 85% water mix, in view of the gradual development of a worldwide company standard for ethylene glycol-based engine coolant. Domestic coolants that succeed in passing the severe test generally contain phosphates, an inhibitor not used in European coolant formulations. There is no evidence of severe cavitation-erosion damage of aluminum water pumps in service in either Europe or the United States, prompting this review. Damage obtained in a cavitation prone water pump was determined in order of coolant concentration, temperature, pump rpm, and inlet opening size. Borates were generally included as a pH buffer. Maximum damage effects were found at a concentration of 15% glycol. Reducing coolant temperature increased the severity of damage, and the location of the damaged area changed as the temperature was varied. Not surprisingly, decreases in pump revolutions resulted in reduced cavitation. Effectiveness of inhibitors in reducing cavitation-erosion damage was found to be in the following order of merit: molybdate, phosphate, nitrate, and benzoate. Some combinations of inhibitors were found to be antagonistic to aluminum water pumps. Examining different styles of pumps, damage was found to be completely different, and one design worked well with a nonphosphate commercial coolant where a convoluted style pump was used.

Jordan reviewed the utilization of antifreeze and coolant in the U.S. Army over a period of 50 years. His review covered the particular requirements that the Army has in the different parts of the world, and the development of a military specification MIL-A-46153. For many years, the military antifreeze system consisted of two separate packages, but with the advent of plastic containers there is now no need for this approach. Reference is made to the Army coolant additive package which is useful for servicing vehicles especially in the field. The main aim of the Army is to provide a single formulation for maximum efficiency and simplified logistics.

Weir of Union Carbide explained the use of polarization resistance and the corrosion behavior diagram as a means of determining the effectiveness of inhibitors for aluminum corrosion in automotive coolants. The area of hysteresis in the corrosion behavior diagram is shown to be very sensitive to the degree of pitting obtained with various aluminum alloys. Sample preparation, operation of the equipment, and specific requirements for the generation of the diagram are explained. A number of coolant formulations with different inhibitors are examined to demonstrate the effectiveness of the method. Recognition is given to the fact that the electrochemical method is a laboratory test which does not necessarily encompass all the variables to be found in the multi-metallic environment in an automobile. However, the approach does appear to have merit as a screening method to indicate which inhibitor packages have potential for protection of the engine cooling circuit in ethylene glycol coolant.

Two additional papers, one by O'Callaghan on metal to coolant interface surfaces in an internal combustion engine, and a second by Fiaud et al on the testing of engine coolant inhibitors by electrochemical methods are included in this publication, although not presented at the conference. It was felt that their inclusion was beneficial to the reader in providing the most comprehensive presentation of information currently available on the subject of engine coolants and their testing.

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