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Project Summary

Control of Hydrocarbon Emissions from Gasoline Loading by Refrigeration Systems

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The capabilities of refrigeration systems operated at three temperatures to control volatile organic compound (VOC) emissions from truck loading at bulk gasoline terminals were investigated in this study. Electricity requirements and relative costs associated with systems operating at each temperature were calculated.

Achievable VOC emission rates were calculated for refrigeration systems cooling various gasoline/air mixtures to temperatures of -62°C (-80°F), -73°C (-100°F), and -84°C (-120°F) by estimating vapor-liquid equilibrium compositions for VOC/air mixtures. Equilibrium compositions were estimated using a computer simulation program and the Soave-Redlich-Kwong and Peng-Robinson methods of predicting thermodynamic properties of mixtures. Emission rates were calculated for inlet streams containing vapors from low- and high-volatility gasolines, at concentrations of 15, 30, and 50 percent by volume (22.5, 45, and 75 percent measured as propane). Predicted VOC emission rates for systems cooling various inlet streams to -62°C ranged from 48 to 59 mg VOC/l of gasoline loaded. Predicted VOC emissions were 21 to 28 mg/l loaded for systems operating at -73°C and 8.7 to 12 mg/l loaded for systems operating at -84°C.

Compressor electrical requirements and relative capital costs for systems operating at the above temperatures were estimated for model systems using the results of the computer simulation. Compressor electricity requirements ranged from 0.11 to 0.45 Whr/l loaded depending upon the inlet VOC concentration and the outlet temperature. The electricity requirement to cool vapors to -84°C was estimated to be 54 to 77 percent greater than the requirement to cool vapors to -62°C, depending on the organic content of the inlet stream. The electricity requirement to cool vapors to -73°C is estimated to be 23 to 36 percent greater than to cool vapors to -62°C. The capital cost to build a system designed to cool vapors to -84°C is estimated to be about 9 percent higher than the capital cost to build a system designed to operate at -73°C, which is estimated to be about 12 percent higher than the cost to build a system designed to operate at -62°C.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The primary objective of this study was to investigate the capabilities of refrigeration systems operated at various temperatures to control volatile organic compound emissions from truck loading at bulk gasoline terminals. A secondary objective was to estimate the electricity requirements and the relative capital costs of systems operated at various temperatures.

Achievable emission rates for refrigeration systems were calculated by estimating vapor-liquid equilibrium compositions for hydrocarbon/air mixtures at three system operating temperatures: -62°C, -73°C, and -84°C. Equilibrium compositions were determined using a computer simulation program and the Soave-Redlich-Kwong and Peng-Robinson methods of predicting the thermodynamic properties of mixtures and mixture components. These methods were also used to predict the amount of heat removal required to cool hydrocarbon/air mixtures to the three system operating temperatures. Model refrigeration systems were designed based on the predicted heat removal requirements. Electricity requirements and relative capital costs were estimated for the model systems.

Volatile organic compounds (VOC) are emitted from bulk gasoline terminals as a result of the displacement of gasoline-laden vapors from trucks during truck loading. These emissions are generally controlled by ducting the displaced vapor—a mixture of air and hydrocarbons—to a system which removes the hydrocarbons. One of the techniques which can be used to control these emissions is refrigeration. In refrigeration systems, the gasoline-laden air is cooled to cryogenic temperatures in order to condense the gasoline vapors.

Refrigeration systems currently in use to control gasoline vapor emissions operate at temperatures between -46°C and -84°C. Emissions from refrigeration systems have been tested and range from 30 to 130 mg/l of vapor entering the refrigeration control system. Test data are not available to accurately determine the relationship between emissions from refrigeration systems and system operating temperature or other parameters.

In this study the emission reduction capabilities and electricity requirements of refrigeration systems used to control VOC emissions from gasoline terminals were determined as functions of the refrigeration system operating temperature and the concentration of hydrocarbons entering the refrigeration system. In addition, relative capital costs were estimated for refrigeration systems designed to operate at different temperatures.

Discussion and Procedure

Achievable VOC emission rates were calculated for systems cooling various gasoline vapor/air mixtures to temperatures of -62°C, -73°C, and -84°C. The control systems studied would first cool the mixtures to 4.4°C in a precooler in order to remove most of the moisture present. Vapors from the precooler would then be cooled to -62°C, -73°C, or -84°C in the main condenser. Calculations of controlled emission rates and electricity requirements were performed for inlet streams containing typical low- and high-volatility gasoline vapors in concentrations of 15, 30, and 50 percent by volume.

The lowest achievable emission rate for refrigeration to a given temperature occurs when the vapor and liquid streams leaving the main condenser are at thermodynamic equilibrium. Thus, the lowest achievable emission rate for a given operating temperature can be calculated by determining the equilibrium composition of the vapor phase at that temperature. Equilibrium compositions were estimated using a computer simulation program and the Soave-Redlich-Kwong and Peng-Robinson methods of predicting thermodynamic properties of mixtures. Heat removal requirements to cool gasoline-laden vapors to cryogenic temperatures were also estimated using these methods. The predicted heat removal requirements were used to design model refrigeration systems, which are parametric descriptions of refrigeration systems including equipment sizes, and refrigerant and heat flow rates. The model refrigeration systems were used to estimate electricity requirements to cool the inlet vapor mixtures under study to cryogenic temperatures. The costs of components were estimated for the model systems designed to treat mixtures containing 30 percent by volume hydrocarbons, in order to estimate the relative capital costs of systems designed to cool vapors to various temperatures.

Results

Achievable emission rates were calculated in terms of the mass of VOC emissions per unit volume of vapor entering the control system. Assuming that the trucks being loaded and the ducts carrying vapors from the trucks to the control system are vapor-tight, the volume of vapor entering the control system is equal to the volume of gasoline loaded. The calculated emission rates can be expressed in terms of mg VOC/l gasoline loaded. Note that VOCs are defined by EPA to include any organic compound which participates in atmospheric photochemical reactions. With the exception of methane and ethane, all hydrocarbons present in gasoline vapors are considered VOCs. Thus, VOC emission rates calculated in this study are emission rates of non-methane non-ethane hydrocarbons.

Figure 1 illustrates the dependence of VOC emissions on condenser outlet temperature for inlet air streams containing low-volatility gasoline vapors in concentrations of 15, 30, and 50 percent by volume. Figure 2 illustrates the dependence of VOC emissions on condenser outlet temperature for inlet streams containing 15, 30 and 50 percent by volume high-volatility gasoline vapors. Low-volatility gasolines are generally loaded in the summer, and high-volatility gasolines are generally loaded in the winter. Therefore, for inlet streams containing low-volatility vapors, emissions were calculated assuming an inlet temperature of 27°C; and for inlet streams with high-volatility gasoline vapors, emissions were calculated assuming an inlet temperature of 4.4°C.

Predicted VOC emission rates for systems cooling various inlet streams to -62°C ranged from 48 to 59 mg VOC/l of gasoline loaded, depending on the percentage of hydrocarbons in the inlet stream. Predicted VOC emissions were 21 to 28 mg/l loaded for systems operating at -73°C and 8.7 to 12 mg/l loaded for systems operating at -84°C. As shown in Figures 1 and 2, the logarithm of the VOC emission rate is approximately proportional to the reciprocal of the system operating temperature for a given set of inlet conditions.

Predicted compressor electricity requirements ranged from 0.11 to 0.45 Whr/l loaded depending on the inlet VOC concentration and the outlet temperature. The electricity required to cool vapors to -84°C is estimated to be 54 to 77 percent greater than that required to cool vapors to -62°C, depending on the hydrocarbon content of the inlet stream. The electricity requirement to cool vapors to -73°C is estimated to be 23 to 36 percent greater than that to cool vapors to -62°C. The capital cost to build a system designed

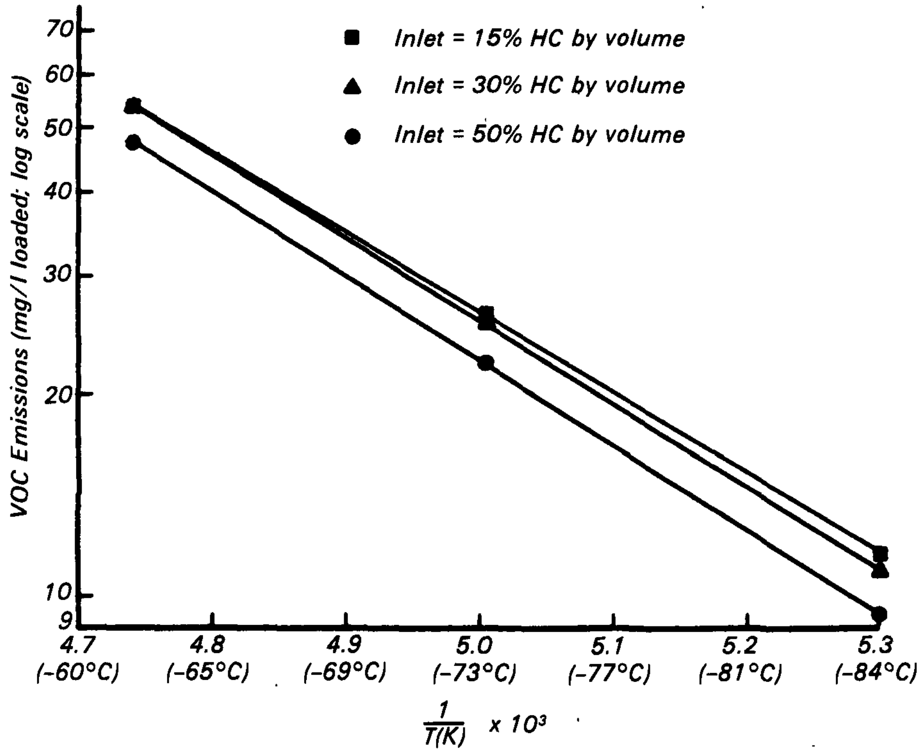

Figure 1. *Effect of condenser operating temperature on VOC emissions — low-volatility gasoline vapors.*

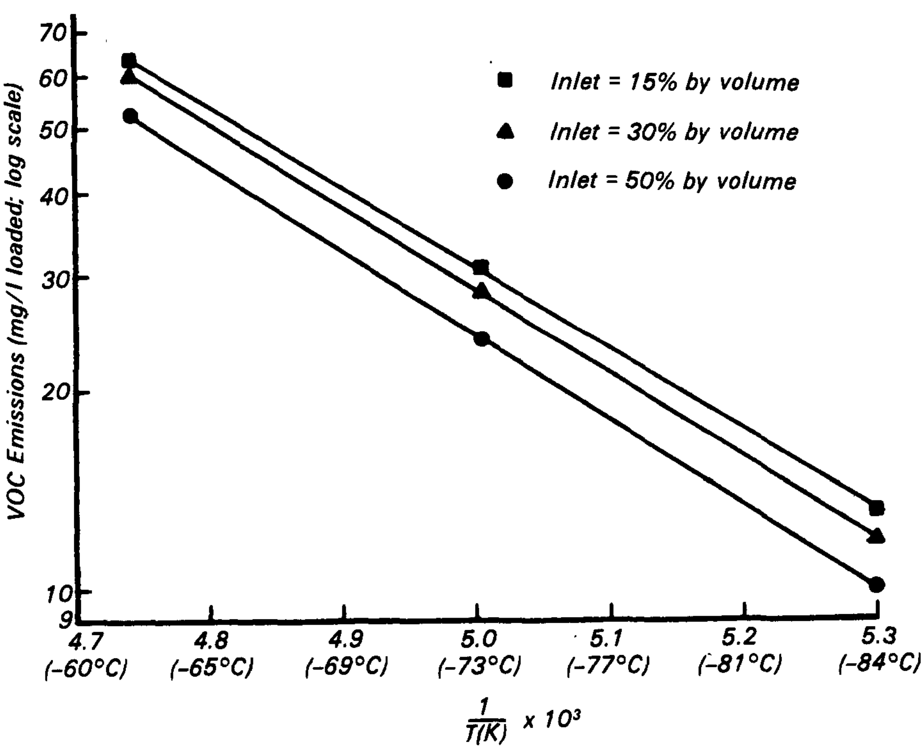

Figure 2. *Effect of condenser operating temperature on VOC emissions — high-volatility vapors.*

to cool vapors to -84°C is estimated to be about 9 percent higher than the capital cost to build a system designed to operate at -73°C, which is estimated to be about 12 percent higher than the cost to build a system designed to operate at -62°C.

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The complete report, entitled "Control of Hydrocarbon Emissions from Gasoline Loading by Refrigeration Systems," (Order No. PB 81-240 335; Cost: $8.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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