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Investigation of emission control efficiency with gasoline vapor recovery units

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Abstract

Increasing environmental regulations and the widespread use of gasoline vapor recovery systems have become a current issue. The development of technology and equipment for the gasoline vapor recovery industry is also growing rapidly and the demands on the relevant technical standards are increasing. Depending on the domestic and international development of the gasoline vapor recovery technology and standard, the purpose of this study will be to examine the VRU systems developed to control the emissions of gasoline-sourced volatile organic compounds. Analysis of the relevant terminology will be carried out through a literature review.

1. Introduction

Gasoline consists of organic compounds obtained by the distillation of petroleum and enriched with various additives. Approximately 71 liters of gasoline can be obtained from 159 liters of crude oil. Gasoline used in industry and transportation has a significant impact both locally and globally. Gasoline can also be released into the environment from leaks and processes during production, transportation, and delivery, from storage tanks, spills, and combustion as liquid and vapor [1].

Volatile organic compounds (VOCs) are among the most common air pollutants emitted by the chemical industries and include hydrocarbons such as olefins, paraffin, and aromatics. VOCs adversely affect air quality and therefore human health. During the distribution and storage of gasoline, VOCs are emitted into the atmosphere by evaporation. The evaporation rate is a parameter dependent on vapor pressure, turbulence, and temperature. VOC emissions are not only an environmental hazard but also a loss of money. For this reason, systems are developed to minimize the amount of evaporation from bulk storage tanks and storage tanks in stations [2].

Gasoline vapor recovery systems are widely used in Europe and the USA. However, these systems have not been given the desired level of importance in Turkey. It is planned that the emissions released to the environment will be controlled by the Industrial Air Pollution Control Regulation. This will increase the need for steam recovery systems [3].

This study will be to examine the vapor recovery systems used for the control of gasoline-derived volatile organic compounds emissions. Evaluation of the relevant terminology will be carried out through a literature review.

2. Material and Method

Gasoline is a worldwide commodity. Carbon dioxide, nitrogen oxides, and hydrocarbons are released as a result of gasoline burning. Emissions from hydrocarbons occur due to evaporation during the storage and distribution of gasoline. Some compounds are released during the storage and distribution of gasoline. These compounds are called volatile organic compounds (VOCs). VOCs constitute an important class of air pollutants and contain different organic compounds. They are pure hydrocarbons, partially oxidized hydrocarbons, chlorine, sulfur, and nitrogen-containing organics. Most VOCs are toxic and or carcinogenic [4].

In the United States, VOCs are defined as any carbon compound that participates in an atmospheric photochemical reaction except carbon monoxide, carbon dioxide, carbonic acid, carbonates, ammonium carbonate. The United Nations Economic Commission for Europe (UNECE) classifies VOCs according to their photochemical ozone generating potential (POCP). POCP is defined as the change in ozone production due to the change in the emission of the VOC [5].

In sunlight, VOCs react with nitrogen oxides to form photochemical oxidants such as ozone. Ground-level ozone is a well-known greenhouse gas. It is an important component of air pollution. Smoke also adversely affects human health and vegetation. Although VOCs and nitrogen oxides occur naturally, anthropogenic sources have greatly increased the concentration in the atmosphere. The sources of VOC emissions are shown in Table 1.

Table 1. Percentage of emission [1]

Emission Sources	%
Industrial and domestic	40
Exhaust gases from motor vehicles	25
Evaporation losses from motor vehicles	10
Gasoline distribution	3
Vehicle refueling	2
Oil refining	3
Others	17

Gasoline distribution and vehicle refueling account for only 5% of total VOC emissions. These emissions are concentrated in gasoline storage stations where people are densely populated. A typical gasoline distribution system is shown in Figure 1.

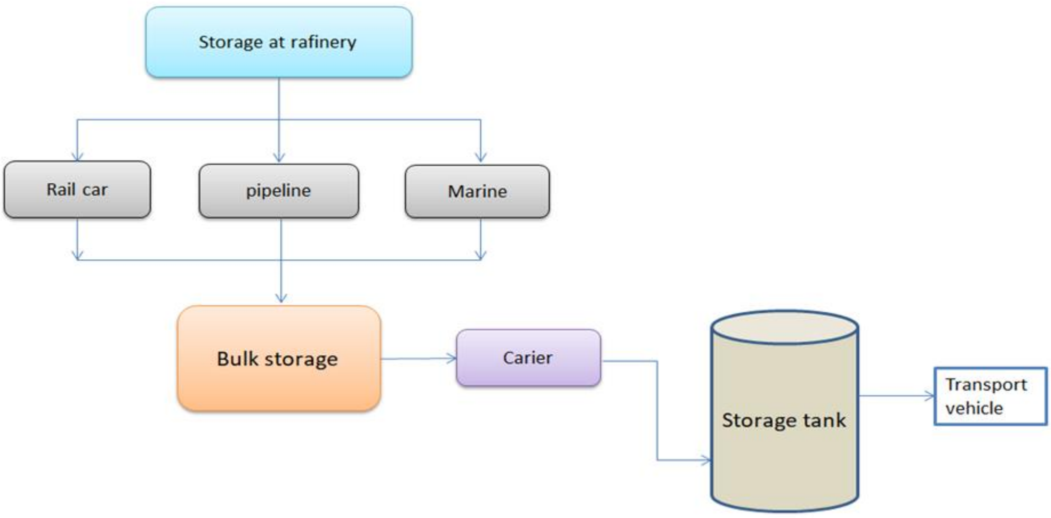

Figure 1. Gas storage and distribution system

The control of emissions from gas storage facilities during the transportation of the final product to the consumer consists of three stages. (Figure 2):

- Stage 1 - Includes the control of emissions at facilities when road tankers are loaded.

- Stage 2 - Includes control of emissions when road tankers are discharged into service station storage tanks
- Stage 3 - It includes the control of emissions generated during vehicle refueling.

During each of these steps, evaporation losses occur as shown in Figure 2 [6]. A product loss occurs unless the resulting vapor contains a VOC / air mixture. The VOC composition is a mixture of compounds with different boiling points of lower molecular weight than gasoline in shown Table 2.

Table 2. Only VOC Typical gasoline vapor composition [2]

Compounds	Volume
Isobutene	8%
n-Butane	10%
Propane	1.5%
Pentane	14%
Benzene	5000 ppm
Hexane and others	6%
Ethane	Traces

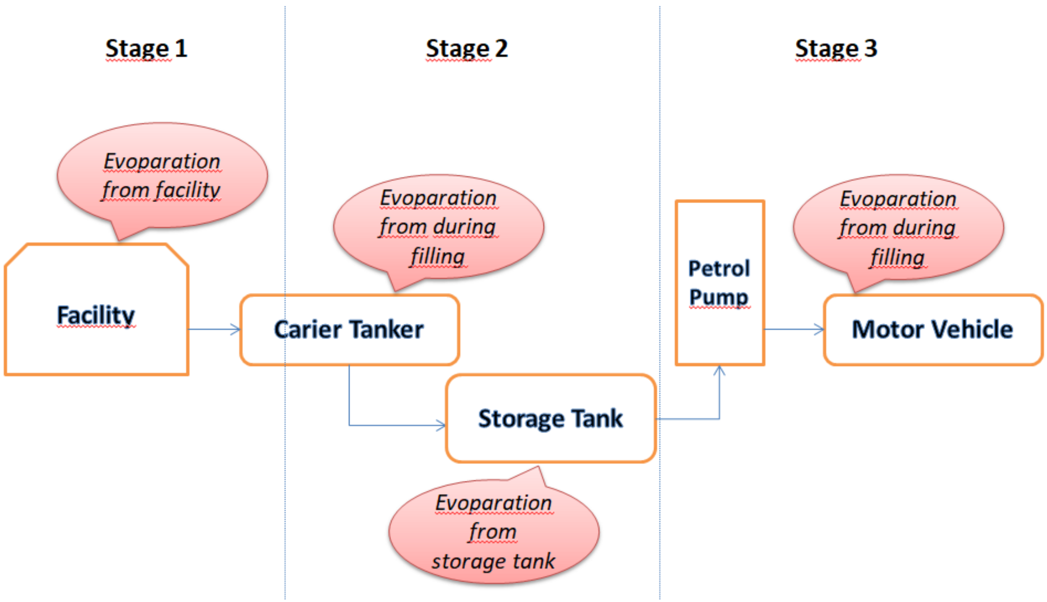

Figure 2. Evaporation emission from petrol storage systems

3. Types of emissions in gasoline storage tanks

Displacement emissions occur in underground storage tanks due to vapor displacement emissions from storage facilities as well as from fixed roof storage facilities. Total emission loss is 0.56% by volume.

Filling emissions result from changes in tank content, temperature, and barometric pressures that cause the liquid and vapor in the tank to expand and contract. Discharging emissions occur when gasoline is pumped out of a storage tank, causing air intake through pressure/vacuum relief valves. The incoming air will dilute the VOC / air mixture previously in the tank, causing an increase in evaporation to restore equilibrium. Filling and discharge emissions from storage tanks account for 0.02% of total emission losses and 0.01% of emissions from station storage tanks.

While refueling a motor vehicle, the incoming gasoline replaces the gasoline vapor in the fuel tank and causes it to escape into the atmosphere. These emissions account for 0.18% by volume of total emissions from gasoline storage and distribution systems [3].

4. Vapor recovery systems for emission control

In this section, steam recovery systems that can be applied to the terminals are examined. The efficiency, reliability, safety, and production capacity of these systems were evaluated.

4.1. Absorption - Compression-Refrigeration Systems (ACR)

ACR works on the principle that gasoline vapor is absorbed under pressure. The first unit in ACR systems conditions the steam entering the absorber. It increases absorber efficiency, reduces heat losses, and increases system safety. Firstly, the inlet vapors are saturated to eliminate explosiveness. Cooling and compression processes are performed before partially saturated vapors enter the absorber. Then the compressed vapors are sucked in contact with the cooled gasoline. Air containing a small number of hydrocarbons passes through the absorber into the atmosphere. Gasoline enriched with light tips is drawn from under the absorber and returned to the fuel storage tanks. The operating conditions in the absorber vary according to the manufacturers. The ambient temperature is -23°C and working pressures are between 3.10 – 14 bars. These values vary depending on terminal operating conditions and vapor storage capacity. The outlet hydrocarbon concentration is determined according to the absorber operating conditions. When the results of the field tests are examined, it has been determined that the values between 1% and 4.5% by volume. Auxiliary compressors can be needed to achieve 90% steam recovery from ACR systems [7].

4.2. Condensation – Compression – Refrigeration Systems (CCR)

The CCR systems work on the principle of condensation of hydrocarbon vapors by compression and cooling. Inlet vapors are saturated above the flammability range in the first stage and then the saturated vapors are compressed. Condensate is drawn from the intercooler. The compressed vapors, together with the condensation coming from the intercooler, pass through the condenser and return to the gasoline storage tank. Hydrocarbon-free air is sent to the condenser. Each manufacturer has slight differences from this basic flow diagram. The operating conditions of the system are temperatures ranging from -23.3 °C to -1 °C and pressures ranging from 5.8 bars to 28.26 bars. These values vary depending on the terminal operating programs and steam storage capacity. Manufacturers report that the recovery rate of the system will increase up to 94% with the equipment to be added according to the operating conditions. The flow diagram of the system is as shown in Figure 3.

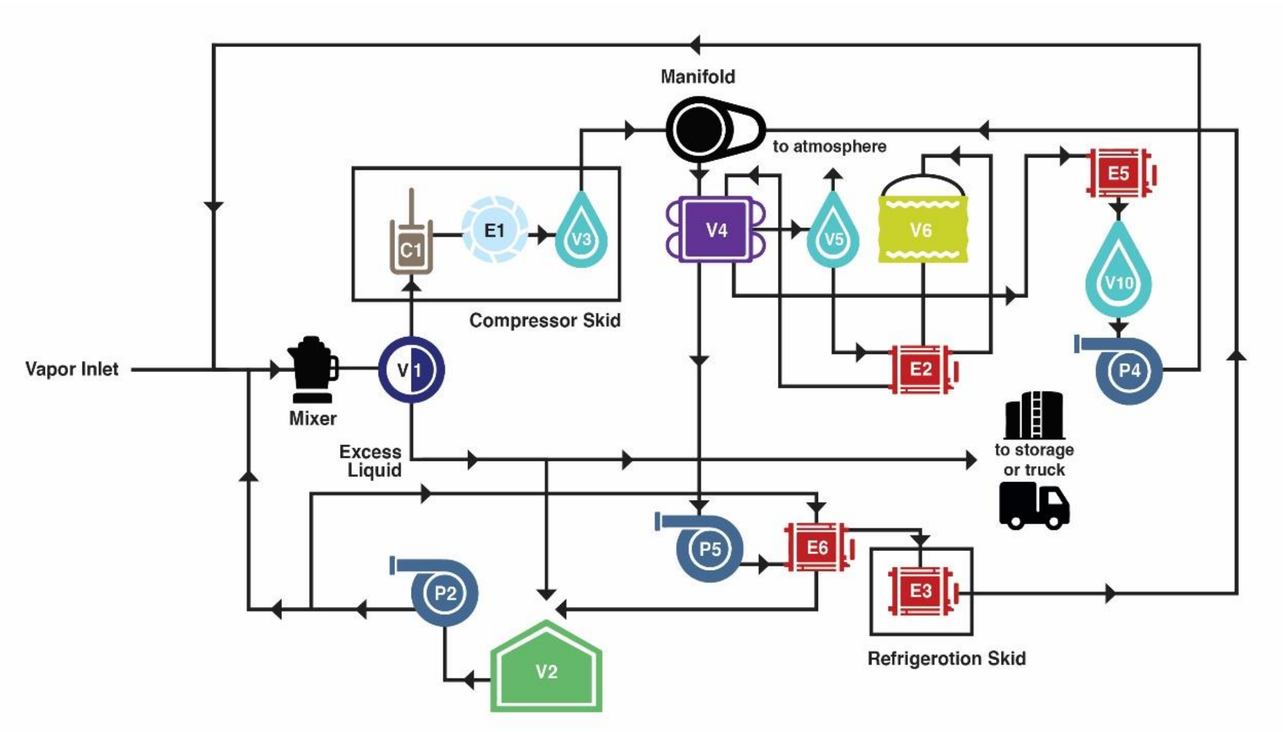

Figure 3. CCR system flow diagram [8]

4.3. Refrigeration Systems (RS)

RS systems work on the principle of condensation of gasoline vapors by cooling under atmospheric pressure. The outlet vapors enter the horizontal finned condenser for cooling to -73°C. Air containing a low proportion of hydrocarbons is sucked from the bottom of the condenser The remaining air is released from the top of the condenser to the atmosphere. Cooling for the condenser coils is provided by a methyl chloride reservoir. A two-stage cooling unit is used to cool the stored brine solution between -76 °C and 51 °C. The vapor recovery efficiency depends on the hydrocarbon concentration of the vapors inlet the system. The field tests data of a system with a capacitor temperature of -73.3 were examined. It was found that the hydrocarbon concentration of 0.6% to 2.6% by volume was stabilized by temperature. With these systems, recovery rates of hydrocarbons vary between 99% and 97% [9].

4.4. Lean Gasoline absorption systems (LGA)

LGA systems work on the principle of absorption of gasoline vapors into lean gasoline. The gasoline vapors are displaced along with the packed absorbent columns. The absorbed air is expelled from the top of the absorbent column. Enriched gasoline is recycled. The lean gasoline for the absorber is produced by heating and evaporating the gasoline in the tank. The separated hydrocarbons are condensed and sent back to the warehouse. The lean gasoline is stored separately for use in the absorption column [10].

4.5. Membrane Systems

MS is a simple and small vapor recovery system for a lower cost separation of gasoline from the vapor mixture. In recent years, several hundred gas stations have used these systems to clean tank vents. The air distributed from the station is collected and sent to the storage tank. When the pressure to be created in the tank reaches a predetermined value, the pressure switch activates the compressor to absorb the excess steam. Some of the hydrocarbon vapors condense and are returned in liquid form to the tank. The remaining hydrocarbon vapors are sent back to the tank as concentrated vapors. Air separated from 96%-98% hydrocarbons is discharged [11].

5. Results

Vapor recovery systems are units with high operational safety. The reliability of these technologies has been proven over two decades of use. Companies using ACR and CCR systems regularly report that the maintenance period is approximately one week a year. Freezing problems have occurred in systems exposed to temperatures below 0°C. Water vapor freezes in the system, preventing the heat transfer of the lines. The solutions for this are as follows [12].

- During closed periods, a part of the system should be turned off and an automatic defroster should be added.
- Methanol can be injected into the system to reduce the freezing point.
- It has been shown that both solutions recommended for the icing problem give effective results. Another important part of ACR and CCR systems is the gasoline vapor compressor.

Safety is of paramount importance in equipment design for working with flammable materials. Vapor recovery equipment manufacturers are aware of this and have included safety features in their designs. Vapor saturators are installed in the systems to prevent the possibility of explosion. The compression ratios and associated off-gas temperatures should be kept at low levels to prevent overheating and spontaneous combustion [13]. Another potential danger in using a vapor recovery system is leaking. Regular maintenance does not cause any security problems [12].

6. Conclusion

Product losses through evaporation create significant losses for companies. At the same time, environmental pollution caused by the uncontrolled release of these vapors is also a potential threat to living things. Reducing material losses, increasing environmental regulations, reducing operational costs and greenhouse gases, and insufficient stocks in the industry and the country have paved the way for the development of products containing various technologies.

Within the scope of this study, the product recovery efficiencies of various vapor recovery systems with different technologies were investigated. Membrane systems have recovery efficiencies of 96-98%, but spare parts, maintenance, and operating costs are high. RS systems provide a recovery rate of up to 99%, while the rate of CCR systems is around 94%. ACR systems provide a 90% recovery rate at high pressures and low temperatures. It has been observed that CCR systems are frequently preferred by businesses, considering the operation, maintenance, investment costs, system control ease, and solutions to the icing problem. It is predicted that the use of these systems will become widespread especially in our country due to environmental safety and economic factors.

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Author contributions

Ece Kalay: Conceptualization, Methodology, Software, Writing-Original draft preparation **Hasan Sarıoğlu:** Data curation, Software, Validation. **İskender Özkul:** Visualization, Investigation, Writing-Reviewing, and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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