CPE-45

Investigation of Temperature Profile for Liquefied Petroleum Gas Storage Operations

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Abstract

The investigation of temperature profile of liquefied petroleum gas during discharging process as the initial step in a usage management of LPG, which is an essential part to evaluate the left over problem. Experiments have been conducted to predict the evaporation behavior of LPG in portable cylinder with 50kg water capacity. In a parallel effort, a computer model has been developed based on the unsteady state of heat transfer concepts using MATCAB 2000 to simulate the evaporation process in the LPG portable cylinder under various conditions taking account such as discharging flow rate and surrounding temperatures. The objective of this paper is a description of the LPG evaporation process and performance of calculation model to investigate the temperature profile. A rather good agreement between the theoretical and experimental data was obtained.

Keyword: liquefied petroleum gas, vaporization, cylinder, heat transfer

Introduction

Liquefied Petroleum Gas (LPG) is unique among the commonly used fuels. It is cheap and offers a great reduction in pollution emissions. Under moderate pressures and at normal temperatures LPG can be transported and stored in liquid form. When released at atmospheric pressure at relatively low temperatures it vaporizes and can be handled and used as a gas. But this cycle includes a drawback that affects the full successful operation of LPG systems. This drawback is the loss due to the residual amount of gas left at exhaustion. It creates problems and unsatisfied conditions. The main parameters influences the system are exhaustion rate, feed composition and ambient temperature. Liquefied petroleum gas in Malaysia is considered quite new, hence the problem of residue in the cylinder was recently identified [1]. The problem occurs when natural evaporation takes place. During the evaporation temperature and pressure in the cylinder will drop to the point that pressure is not able to push out the liquefied petroleum gas from the cylinder at the required level of flow [2]. At that point, normally the pressure in side the cylinder is equal to the atmospheric pressure and the some amount of liquefied petroleum gas still exists in the cylinder [3]. Gas suppliers have received complaints due to the problem. They claimed that, if this problem were not solved then they would suffer losses. Therefore, suppliers must look seriously about the related problem because customers have the right to do so [4]. The quantity of residue in cylinder with 50 kg water capacity is 5.78 kg with the composition of propane 2.17 percent and butane 97.82 percent by weight respectively [3].

The general term "vaporization" refers to the conversion of liquid to vapor, when it takes place at an interface between a liquid and its vapor it is referred to as "evaporation". Vaporization is a process where the molecules at the interface runaway from the liquid phase to the gas phase at temperature below the boiling point of the liquid. This phenomenon can be occurred at any temperature [5]. Evaporation of liquid stored in a closed cylinder can be considered as the same as boiling phenomenon. During the process, molecules at the liquid interface have enough energy to overcome attraction forces from molecules around it and consequently it moves to the gas phase. Vaporization of LPG can be defined as an evaporation that occurred due to the pressure drop caused by the gas exhaustion from a closed container. During this process, heat required for vaporization is supplied partially from the liquid phase and the surrounding [6]. This article deals with the LPG continuous exhaustion operation. Parameters that expected to affect the system behavior, such as the exhaustion rate, ambient temperature and feed composition, are discussed. The theoretical results are compared with experimental results.

Approach and Method

Experimental

This study involved the fabrication and installation of simple apparatus as shown in Figure 1. The rig basically was referred to the study method done for a small size of cylinder [2]. However, few modifications were made, such as the number and positions of the thermocouples, control of surrounding temperature and flow meter arrangements as well as the additional on line gas chromatography. Fuels used were mixtures of propane and butane in weights percentage. The mixing of the components of butane and propane into the cylinder was followed the standard procedures. The simplified procedures for the experiment were started with setting up the surrounding temperature and upon stabilize the valve was opened until the flow meter gave readings of flow rate under study. Temperature data was taken through interface system for every interval of 10 minutes for 4 hours and every hour after the period of 4 hours to the end of the experiment. The experiment was continued until the pressure in the cylinder reached zero psig.

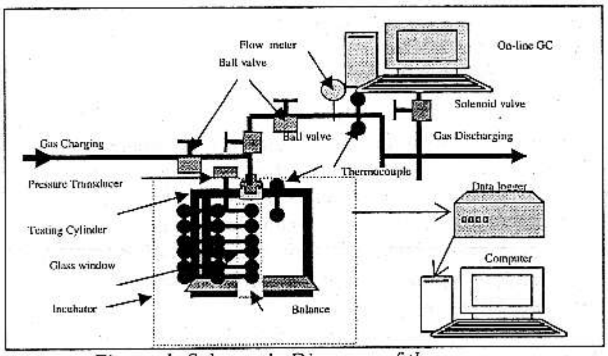


Figure 1. Schematic Diagram of the Testing Rig

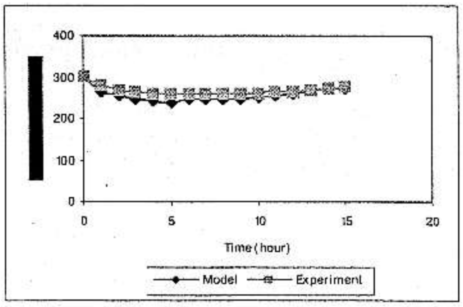
Theoretical Model

There are many models for description of behavior of the LPG vessel but not even in single one discussed about LPG vaporization behavior related to left over. Therefore, in this study, a simple theoretical model is proposed, which gives the main features of an influence of temperature profile to the left over problem. A model of the process is first developed based on readily available experimental data. The models are developed based on the basic material and energy balance law. Models are solved with MathCad Professional Software by employing the Fourth Order Range-Kutta method to solve for the system of differential equations.

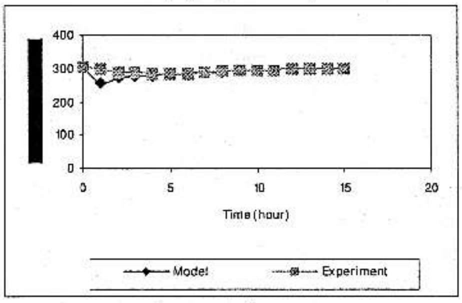
Results and Discussion

The results shown were involved the effect of composition, flow rate and surrounding temperature. Relationship between temperature profile and the quantity of residue will be discussed. Even though, there are a lot of temperature sensor used to record the liquid LPG temperature in the test cylinder but the lowest and the upper sensors was selected that used to compare with the reading given by the model. This concept is to make sure that the temperature recorded is always by the sensor in liquid phase and vapor phase. This is because the reading recorded by the model is the temperature of bulk liquid and bulk vapor. Furthermore, the result of temperature profile only highlighted for test parameters at constant flowrate and surrounding temperature but varies with LPG compositions.

Figure 2 until Figure 5 are temperature profile of liquid and vapor temperature of LPG at different initial composition under different discharge flow rate and surrounding temperature. A rather good agreement between the theoretical and experimental data was obtained. This is due to the pattern of temperature changing which is will reduced at the initial stage but will increased latter.



(a) Liquid Temperature

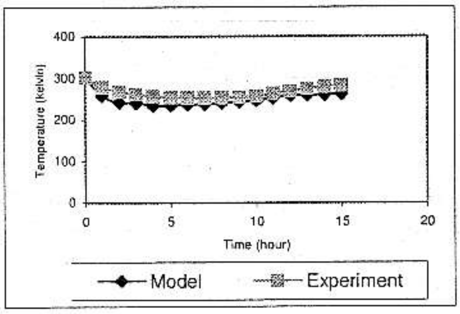


(b) Vapor Temperature

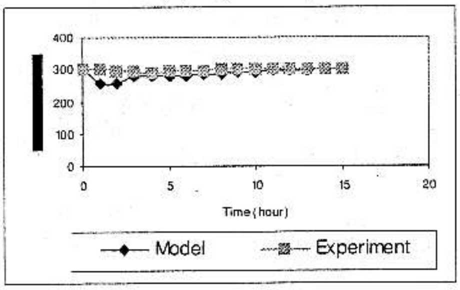
Figure 2- Liquid and Vapor Temperature of Mixture 40/60 at Surrounding Temperature 30°C and Discharge Flow rate 10m³/hr

However, the result based on model is slightly lower than experimental for both phases. The different may be due to the fact that ice layer that exist on the cylinder is assumed constant thickness were as the actual condition the thickness of ice layer is thicker in the bottom part. This theory is almost valid if we look at to the vapor temperature profile while the different is too small except the early stage.

The patterns of the temperature readings for all compositions were similar. The lowest readings were recorded by the thermocouple positioned at the most bottom. This was because of during evaporation process; the heat required was from the surroundings and from the liquid itself [7]. The latent heat of evaporation was from two sources for a short period, but with time the source was only came from the liquid. Although the fact that heat was still supplied by the surroundings but it was in a small quantity due to resistance to the formation of ice on the outer wall of the cylinder.



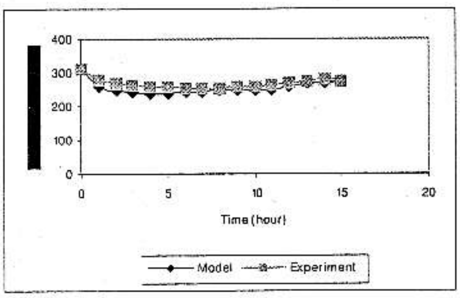
(a) Liquid Temperature



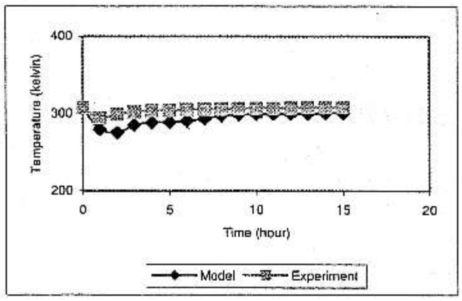
(b) Vapor Temperature

Figure 3- Liquid and Vapor Temperature of Mixture 80/20 at Surrounding Temperature 30°C and Discharge Flow rate 10m^3/hr

Based on the Figures, cooling was seen terrible for the first period of two hours. Further evaporation process will further decrease in temperature. Although there was also a decrease in temperature at thermocouple in vapor phase for the first 1hour, but the reduction was due to discharge of cool vapor. At the end of the experiment, all temperature readings were tending to reach a control temperature, which is surrounding temperature of cylinder.



(a) Liquid Temperature

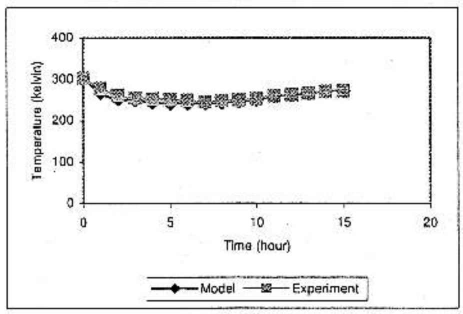


(b) Vapor Temperature

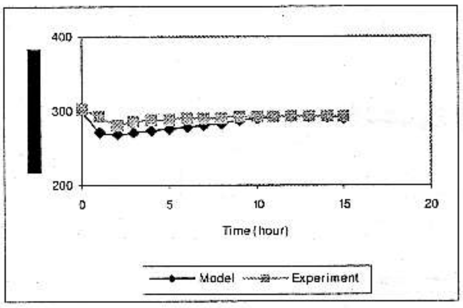
Figure 4- Liquid and Vapor Temperature of Mixture 80/20 at Surrounding Temperature 35°C and Discharge Flow rate 10m^3/hr

The thermocouple will turn the position in other phase when the increase of temperature in sudden. This condition was due to heat needed for evaporation only from the liquid content and not the vapor content.

The role of temperature on vaporization process was determined by comparison of temperature readings recorded in liquid phase. This was because thermocouple in liquid phase continuously recorded the liquid temperature and the lowest temperature until the cylinder was almost empty. If temperature readings in liquid phase were close to boiling point or dew point temperatures, vaporization would be very slow and might stop if temperatures were below those point temperatures [8]. At this point, there is no more LPG will vaporize and will end up with residue in the cylinder. Therefore, to minimize the left over problem the liquid temperature must be avoid from reach to boiling or dew point.



(a) Liquid Temperature
(b)



(b) Vapor Temperature

Figure 5- Liquid and Vapor Temperature of Mixture 80/20 at Surrounding Temperature 30°C and Discharge Flow rate 5m³/hr

Furthermore, the design of cylinder LPG needs to look in to this factor.

Conclusion

This study has enabled to determine the temperature profile of LPG that required minimizing the left over problem in the cylinder using heat transfer concept. The results obtained have shown the importance of the understanding of parameter that involved maximizing the heat transfer from surrounding into the LPG cylinder. The experimental and theoretical results obtained indicate an acceptable agreement.

Acknowledgement

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