Design Specification

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0.1	2023-09-15	First draft.	Group	Theodor Vallgren
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1 INTRODUCTION

This document is about the design of the system controlling the purging of the evaporation system of a gasoline tank of a vehicle. This project is carried out at Linköping University in the CDIO-project course along with Aurobay and the Vehicular System division (ISY, FS).

1.1 Definitions

Charcoal canister: Contains active coal and its mission is to adsorb the hydrocarbon vapors so that it does not escape to the environment.

Stoichiometric combustion: Stoichiometric combustion refers to the ideal chemical reaction in which a fuel and an oxidizer (typically oxygen in the air) are mixed in precise proportions so that all the fuel is completely consumed with no excess remaining. In other words, it's the perfect balance of fuel and oxygen required for every fuel molecule to react fully with oxygen, resulting in complete combustion.

EVAP-system: Evaporative Emission Control System

1.2 Purpose and Goals

The purpose of this project is to investigate the purging of a charcoal canister. This would improve the process and thus help the customer Aurobay to release a better product for their customers. Aurobay can thus stay at the forefront of market-leading technology, improving the customer's economy. The specific long-term goal is to examine and improve the purging process of the charcoal canister, which can enhance the overall emissions of the system it is installed on.

The short-term objectives for this project are therefore as follows, to achieve the aforementioned long-term goals:

1. Design a regulator to control the purging cycle of the charcoal canister while maintaining flow requirements.

2. Commission laboratory equipment.

3. Model the hydrocarbon flow through the charcoal canister.

4. Regulate the EVAP flow for an arbitrary purging cycle.

5. If possible, demonstrate the EVAP system in the university's engine test cell.

2 SYSTEM OVERVIEW

This section will briefly introduce every part of the system.

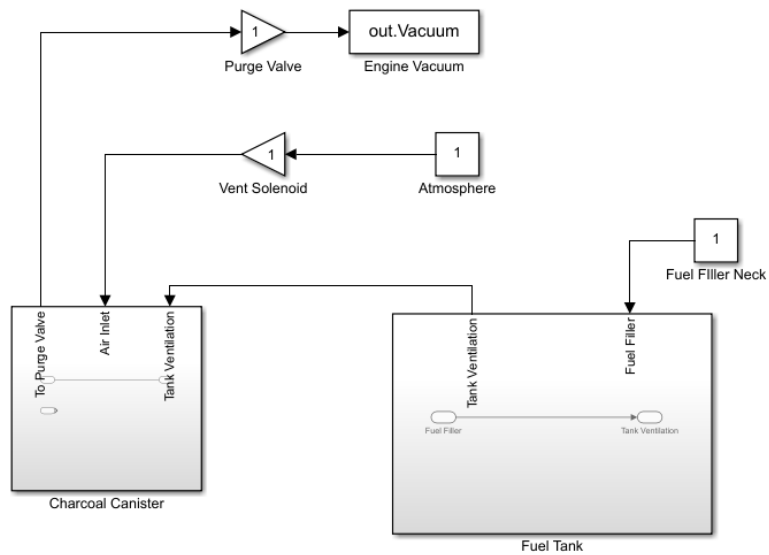An approximate layout of the system for a car could be seen in Figure 1.

Figure 1: A schematic of what an EVAP-system looks like in a vehicle.

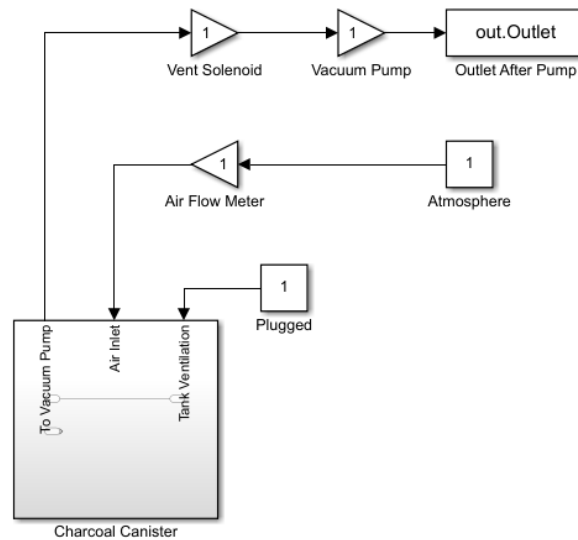The testing rig schematic for this project are presented in Figure 2.

Figure 2: The test rig in the standard configuration without our sensors.

2.1 EVAP system

The EVAP system must be modeled using mathematical models to create a program that can utilize data from the sensors as input and output control signals to the control system. The goal is to model the flow of fuel vapor, but to do this several parts of the system need to be taken into consideration.

2.1.1 *Charcoal canister*

A charcoal canister, also known as an evaporative emission canister, is a crucial component in modern automotive systems designed to capture and manage fuel vapors produced by the vehicle's fuel system. Its primary function is preventing these harmful vapors from being released into the environment. [1]

2.1.2 *Servos*

Servo fundamentally involves amplifying or transferring the force you use to where it should operate using a motor or another external force. Servos are used in many applications and can vary in size. For our application, it will mainly be used to open and close valves during the purge.

2.2 Control System

The system is controlled using a custom-made system supplied by Aurobay, and thus no changes will be made here. The control system must, however, be used to input control signals to the engine and is used both for testing and validation.

2.3 Data Acquisition

The data acquisition will be done in several steps, which are further described below.

2.3.1 *Arduino*

Arduino is a small open-source computer that is very cheap and efficient at collecting data from sensors. The Arduino can be connected to the computer via USB, or in some cases Wi-Fi. Programs are encoded using Arduino's own coding language, which is based on Wiring and C++ [2]. This project uses an Arduino Nano 33 IoT, which is pre-installed with a module to allow data transfer via Wi-Fi.

2.3.2 *Raspberry Pi*

Raspberry Pi is a more powerful computer than Arduino, but still not as powerful as for example a laptop. The Raspberry Pi is often used to collect data and modify it to for example plot graphs or in other ways process the data. There are full operating systems available to install complete with a GUI to simplify for the user [3].

2.3.3 *Sensors*

A sensor is a device that detects and responds to some type of input from a physical environment. There are several different types of sensors that are able to measure pressure, temperature, and flow. This project will use sensors to measure flow (Figure 5), temperature (Figure 3), and pressure (Figure 4). One sensor that measures flow and one valve that controls the airflow are located in the control box (Omniprocess F-112AC-M10-AAD-44-V and Omniprocess F-004BI-IVU-44-V respectively). These are located in the gray box provided by Aurobay and is not components that this measurement system controls or monitors. The flow sensor inside the box enables a total readout of air-volume to be displayed along and is what the control system utilizes to regulate airflow.

Table 1: Sensor data.

Sensor	Pressure	Temperature	Flow
Name	Piezoresistive (PR) differential pressure transmitters for harsh environments, Kistler 4264A	Kmeter Isolation Unit with Thermocouple Temperature Sensor (MAX31855)	Sensirion SFM3000-200-C
Measurement unit	bar	°C	l/m
Operating range	± 0.17	-200 - 1350 °C	± 200 l/m
Limit	0.51 bar	N/A	1 bar
Resolution	N/A	0.25 °C	N/A
Accuracy	0.1%	± 2%	± 1.5%
Electrical interface	0-5V 4-wire MIL-DTL-26482	I^2C	I^2C
Physical interface	M10x1 male	N/A	⌀ 19mm Hose

Figure 3: The temperature sensor used in the experiments.

Figure 4: The pressure sensor used in the experiments.

Figure 5: The air flow sensor used in the experiments.

3   EVAP SYSTEM

Below this, and the following 3 sections, a more in-depth description of the system and the subsystems can be read.

To create a model where we request a flow of fuel and in turn control the EVAP system the fuel flow must be modeled. Research suggests that the emptying of fuel in the canister generates a temperature difference in the canister [4], this can be used to determine the concentration of fuel vapor in the canister. The model will be a function depending on the purged airflow (q_{ac}), the amount of fuel in the canister (m_{fc}) and the surrounding temperature (T_{env}). The output will be the amount of air-fuel mixture that later is provided to the combustion engine. The expected output of model for the EVAP-system is believed to be a second-order system which can then be controlled with a regulator.

$$f(q_{ac}, m_{fc}, T_{env}) = model$$

4   HARDWARE

A laboratory setup of the EVAP system will be used, where the canisters are already filled with n-butane, and using a vacuum pump the butane will be sucked out from the canister and pumped into a fume hood.

To allow measuring two flow meters are installed in the EVAP-system, one measuring the inlet air and one measuring the mass flow out from the canister.

Furthermore, there are twelve temperature sensors available which will be drilled into the canister to measure the temperature in various locations of the canister. Lastly, one pressure sensor is available, this will be placed either on the inlet or the outlet of the canister.

5 CONTROL SYSTEM

The system comes with a custom-made control system, which will be used to implement the control parameters.

6 DATA ACQUISITION

The following section describes how the data will be processed.

6.1 I^{2}C

I^{2}C is a protocol used to communicate between several micro-controllers. The protocol has the major benefit of requiring only four wires between the controller and a sensor, more sensors can be added by daisy-chaining the sensors. The unit receiving data is usually denoted as Master and the senders as slaves. [5] The protocol requires power and ground on two of the lines, the remaining two are SDA and SCL respectively. SCL is the clock line, this is used to prohibit data transmission while the master is occupied receiving data from another slave. SDA is used to transmit the data. [6, 7]

6.2 Collection of data

To read the temperature in the canister several KMeterISO units will be placed on the canister. These sensors are equipped with their own micro-controllers and thus can be connected to the Arduino via the I^{2}C protocol through several Grove I^{2}C hubs. In table 2 the connections used on the Arduino to measure the sensor data are described.

Table 2: Connection pins used on the Arduino

Pin	Signal	Description
5V	Power	Power to the sensor. [1]
GND	Ground	Ground to the sensors
D18	SDA	Data line
D19	SCL	Clock line

6.3 Transferring data to the Raspberry Pi

The Arduino will collect all data from the sensors and send them over to the Raspberry Pi 3B+ using the UDP protocol over a wireless connection. Lastly, the Raspberry Pi will log the data into a CSV file and plot graphs, which will all be saved to the SD card.

7   DATA FOR RANGE OF OPERATION

In order to make sure that the experiments are conducted at reasonable operating ranges for a vehicle the purge mass flow is calculated from typical intake manifold mass flows.

Operation	Intake manifold pressure
At idle	30-60 kPa
At part-throttle cruising	40-80 kPa
At wide-open throttle	80-100 kPa or more

Table 3: Typical intake manifold pressures for a turbocharged engine for various operation ranges

8   EXPERIMENTS

The experiments conducted during the project will be executed and evaluated in several stages. These experiments will be further developed as the project continues. The different experiment plans are described below.

8.1   Initial experiment plan

To gain a better understanding of the carbon canister the initial experiments will be conducted with temperature, air flow, and pressure sensors to measure all behaviors of the canister. The initial experiments will use an airflow through the canister of 30 [L/min] which corresponds to normal stationary driving at 50 [km/h](At part-throttle cruising). Below is an equation that tells the mass of air that is sucked in to the cylinders.

$$\dot{m}_{ac} = \eta_{vol} \frac{V_D N p_{im}}{n_r R T_{im}} \tag{1}$$

where η_{vol} is the volumetric efficiency for the engine, and is defined as:

$$\eta_{vol} = c_0 + c_1 \sqrt{p_{im}} + c_2 \sqrt{N} \tag{2}$$

and the parameters is set to: $c_0 = 0.2677, c_1 = 0.0013, c_2 = 0.0174$ These parameters comes from a 2 liter turbocharged Volvo engine. At idle the pressure in the intake manifold i assumed to be around $40kpa$, the temperature around $20\,^\circ$ C and the engine speed around $900rpm$. This means that the mass air flow into the cylinders should be around 7,1[g/s].

8.1.1   *Temperature measurements*

To gain an overall understanding of how the temperature changes in the canister when purging the first experiment will use all twelve of the temperature sensors, scattered in a grid network across the canister. The placement of the temperature sensors can be seen as the red dots in figure 6.

Figure 6: Picture of the canister with temperature sensor placements illustrated by the red dots.

8.1.2 *Air flow measurements*

Ambient air is sucked into the canister while purging. In the current setup, there is already a sensor mounted at the outlet of the canister. The main purpose of this sensor is to assist the controller of the purging. There will also be an external sensor measuring the airflow, which will be mounted at the end of the inlet hose. This means that no major changes have to be made to the current setup. The purpose of the external airflow sensor is to collect data for the Arduino and Raspberry Pi to later evaluate and compare with the collected data from the setup.

8.1.3 *Pressure measurements*

Since the system works with a low-pressure side from the inlet air to the engine in order to suck the air-fuel mixture from the canister the pressure difference should be small. In order to evaluate this and measure the pressure difference the pressure sensor will be placed at the air inlet connection of the canister. The sensor will be placed after the filter as close to the canister as possible.

8.2 Secondary experiment plan

Iterate the test plan over time, as per the customers request.

9 FUTURE WORK

The scope of this project is to find a model for the desorption of hydro-carbons in the charcoal canister. This work is meant to be used in real-life vehicles to obtain a desired lambda value within the engine. Therefore, future work should implement and test the model for vehicles in real-life scenarios to verify that the model is functioning as desired.

The model will also be obtained in stable conditions with little variation in temperature, ambient pressure, etc. Therefore, future work should also expand the model to function for various conditions that a vehicle may be exposed to, for example, lower ambient pressure at high heights or varying temperatures as seasons change.

A easily operated test bench with all components in a setup so a new user could use it for future work.

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