Fluid Power System Design for Super-Gas™ Fueling Stations

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ABSTRACT

The Composite Fuels Laboratory at the University of Oklahoma has designed and built two new fueling stations to produce and provide an alternative fuel, trademark Super-Gas™ to be used for vehicle propulsion. Two fluid power systems have been designed and adapted to accomplish these requirements. Both the fluid power system and the automatic controller control the processes to produce Super-Gas™ in a safety and reliable way. This paper will present the fluid power circuits and controller designs for the particular fueling stations. This design system has the capability to either produce the fuel on board the vehicle (BOB) or transfer it to the vehicle tank as a common fueling station. Super-Gas™ is a liquid fuel mixture composed of a light hydrocarbon and compressed natural gas and it has some characteristics that make it behave as a hydraulic fluid.

Super-Gas™ made using the bubbling on board type design (BOB) produces 10 Gallon of the mixture in approximately 8 minutes on board the vehicle. A diaphragm pump was used to transfer the light hydrocarbon (LPG). The fast fuel design (FFS) has shown to produce the same amount of fuel in a time range from 5 to 7 minutes, but at any vehicle tank pressure, without reduction in the volumetric efficiency as long the circuit controls the flashing issue. It uses a basic concept of a drive piston pump.

The paper will discuss technical hurdles that remain for improving the designs.

KEYWORDS

Alternative Fuel, Fluid Power Control, Super-Gas™
INTRODUCTION

The University of Oklahoma has patented [1,2] a new alternative fuel for motor vehicle propulsion.

This new fuel, which is a liquid mixture of Compressed Natural Gas and a light hydrocarbon in this particular case Liquefied Petroleum Gas, has been trademarked Super-Gas™. The fuel can offer to CNG users increased vehicle range while maintaining both economical and environmental superiority. The user will gain higher fuel energy density by utilizing Super-Gas™, which translates into both increased power and more range per unit volume.

Two prototype hydraulic circuits were designed and tested to produce the mixture-liquid fuel. They showed to be safe and reliable. However, the volumetric efficiency of the hydraulic circuit to transfer Liquefied Petroleum Gas (LPG) and the mixture LPG, CNG showed to be low.

Fast Fill (FFS) and Bubbling on Board (BOB) fueling station were designed with different types of hydraulic circuits but they share the same concept to produce and deliver the fuel to the previously converted vehicles for testing purposes [4].

Bubbling on Board hydraulic design uses a diaphragm positive displacement pump to transfer LPG into the low-pressure vehicle tank; where is mixed with CNG later on.

Fast Fill design uses a customized driving piston pump to transfer LPG as well as the mixture fuel (Super-Gas™) from a storage fuel tank under high pressure to the vehicle fuel tank.

1. Hydraulic Design for Bubbling on Board Concept

Early stages of the design process made use of a conventional gear pump with 6.38 cc/Rev (0.388 in³/Rev). The results showed that with LPG as hydraulic fluid this pump rapidly lost volumetric efficiency as the pressure increased. Furthermore, due to the low viscosity of the LPG, the internal parts of the gear pump rapidly suffered oxidation. Therefore, a high-pressure diaphragm pump was chosen with 10.51 cc/Rev (0.641 in³/Rev). The result showed this pump to be able to pump LPG from a tank under 10.2 Bars (150 PSig) and transfer through the piping into the vehicle tank. See Figure 1 above.

![Figure 1. BOB Hydraulic Design](image)

City Gas Explosion proof Unit BOB

CC1 Tanks Array CT1

Filter

PROPANE 100 Gallons at 150 Psi

CT2

Pump

MOV

MOV

Quick Connect to fill

Flex. hose to vehicle tank

The filling time can vary due to the initial pressure in the vehicle tank. The lower the pressure in the vehicle tank, the faster the filling time with LPG is. The volumetric efficiency of transfer LPG is around 47% as described in table 1.

The efficiency of LPG transfer to the vehicle tank is low due to the flashing phenomenon occurred by loss of pressure. However, this system proved to be reliable and safe. Some problems were found when the vehicle tank had a remaining high pressure in its tank, greater than 28 Bars (400 PSig). This system could not overcome the above pressure and there was no satisfactory pumping of LPG into the system. Therefore, for this prototype to work well, it required the vehicle tank pressure be lower than 10.5 Bars (150 PSig).

2. Hydraulic Design for Fast Fill Station Design

The primarily purpose of the hydraulic design for the fast fill station was to increase production of Super-Gas™ by batch-production as well as reduction of delivery time to vehicle tank. This hydraulic circuit has a conventional fluid power unit of 4.8 KW (7.5 HP).

This power unit provides the power to drive a piston pump with an array of check valves with low-pressure drop and 0.023 Bar (1/3 PSI) of cracking pressure with an ID diameter of ¾ inch.
The volumetric displacement of the hydraulic piston pump is 2324 cc/cycle (141.833 in³/cycle). The flow rate profile (Figure 2) shows to be oscillatory due to the reciprocal motion of the piston pump. The average volumetric efficiency for transfer of LPG is 25%. This very low value is due to the flash phenomenon of the LPG inside the pipe. The average measured flow rate is 6700 cc/Min. (1.77 Gal/Min) taken from Figure 3.

Rotative motor operator valves were used rather than conventional solenoid spool valve, because of low viscosity of the LPG and Super-Gas™ fluid. Most of the high-pressure pipe was selected to ½ inches OD diameter stainless steel.

This design has the following main hydraulic features:

1. Branch hydraulic circuit to pump under pressure LPG to the mixing tank.
2. Branch hydraulic circuit to inject CNG into mixing tank creating a bubbling (mass transfer) process in the storage tank.
3. Branch hydraulic circuit to pump the mixture into the vehicle tank.
4. Additional circuit to recycle the vapor from the venting port from the vehicle tank. This circuit prevents overfilling the vehicle tank.

2.1 Description hydraulic circuit. FFS

The main concept behind the Fast Fill station (FFS) is to pre-mix and store Super-Gas™ for later vehicle fueling. The vehicle to be filled may have any size tank, initially filled to any level or pressure. Sufficient backpressure (600 PSIg) is added to the vehicle tank to prevent flashing (See Figure 4). The speed is controlled by the needle valve. Once the filling process is started, the pressure differential helps to transfer the fuel. Therefore, the efficiency during pumping Super-Gas is high, as shown in table 2. Upon the pressures are equalized the efficiency is dropped down to 75%. The time for pumping the fuel (11.8 Gallons) is around 100 seconds. The fill tank is continually vented to the station during the fill. The amount of mixed fuel delivered is continually monitored and the formation of a thermodynamic liquid plus vapor mix is sensed external to the vehicle in the vent line. This entire process is accomplished through a series of fluid power devices and sensors as shown below in Figure 5.
Table 2. Fast Fill Hydraulic Performance

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<tbody>
<tr>
<td>LPG</td>
<td>2.3 (0.613Gall/cy)</td>
<td>34.095 (9 Gail)</td>
<td>62 cycles</td>
<td>305</td>
<td>25</td>
</tr>
<tr>
<td>SGAS</td>
<td>2.3 (0.613Gall/cy)</td>
<td>44.70 (11.8 Gail)</td>
<td>21 cycles</td>
<td>95.79</td>
<td>87</td>
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The fast fill station uses a power unit with a hydraulic gear pump: Cv=9.5 cc/rev (0.6 cu inch) and an actuator with a piston diameter of 6.35 cm (2.5 inch) and rod diameter of 4.44 cm (1.75 inch), which in turn gives an average of cycle time of 4.88 sec/cycle including shift time of the electro-hydraulic valve as well as the build up time of the hydraulic pressure.

The dimensions for the driven Hydraulic Pump cylinder are: piston diameter of 8.25 cm (3.25 inches), rod diameter of 4.44 cm (1.75 inches) and stroke is 25.4 cm (10 inches). The pressure showed at figure 4 is read from a sensor located at position 7 (figure 5). After the Super-Gas™ pumping start time the pressure become fluctuating because of reciprocal motion of cylinder.

The user inputs the desired value of Super-Gas™ into the panel operator.

The PLC turns on the pump, opens the respective valves, and begins measuring the flow from the flow meter until the chosen amount of fuel is reached. The DL240 has maximum of 3.8 KB of memory comprised of 2.5 KB of ladder memory and approximately 1.3KB of V-memory (data register). There are 129 instructions available for program development and a maximum of 128-point local I/O and 896 points with remote I/O are supported.

Program storage is in the EEPROM, which is installed at the factory. In addition to the EEPROM, there is also a RAM on the CPU, which will store system parameters, V-memory and other non-applicable. The DL240 CPU has two communication ports. Their communication protocols are RS232C.

3.1 Design of Control Logic

The PLC controls all the actuators and reads the information from the capacitive sensor, pressure transducers, frequency (Flow-meters), limits switches, and push buttons. This design [6] allows connecting the PLC to a computer for programming purposes. Furthermore, a panel operator is wire-linked to the controller in order to allow the user to establish the fuel amount required for the testing vehicle tanks.

Using the programmable computer, the entire sequence of coded instructions that control the system’s performance (Fuel Station Performance) can be easily modified, thus saving time.

The PLC used for this application is a Direct Logic 205 with a 240 type CPU made by Koyo® [6]. Inside the microprocessor, there is a Hitachi® eight bit family micro controller. This medium-sized DL205 family is powerful enough for this development.
5. Results & Discussion

The hydraulic design for the prototype station has shown to be a reliable and safe design to produce Super-Gas™ fuel and the use of PLC show to be effective way to control these systems. Experimental and computer testing have demonstrated that making a batch of Super-Gas™ using 0.038 m³ (10 US gal) and 2.2 ACF¹ of CNG will produce a volume of composite fuel near to 0.063 m³ (16 US gal) in less than 7 minutes. For both fuel stations.

The low viscosity of Super-Gas™ has produced adverse effects in the station equipment, especially the wear of the hydraulic cylinders and seals, as seen in Figure 5. This figure shows the pumping system of the fast fuel station. This setup was used to determine the amount of wear in the cylinder after 10³ cycles. Also shown in Figure 5, Super-Gas™ incidence on the pump was minimal. However, corrosion and oxidation is present due to poor lubricant properties of the fuel. It is too soon to conclude about the effects the fuel has on the cylinder; more analysis must be performed to verify the elements performance in a long-term period.

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¹ 2.2 ACF approx 400 SCF
Flashing is a key problem for this kind of system, therefore in order to increase the volumetric efficiency to transfer LPG and Super-Gas\textsuperscript{TM} resizing of the inlet pipes is necessary as well as design of a new pump to work with a low viscosity and two-phase fuel.

**CONCLUSION.**

Modifications to the hydraulic circuit of both fueling stations have been done through research and experimentation. The success of these developments has contributed to the safe, efficient, and reliable production of Super-Gas\textsuperscript{TM}.

One major improvement is the pre-filling concept used to prevent flashing. Bringing the pressure up in the vehicle tank with CNG before filling with Super-Gas\textsuperscript{TM} has greatly reduced the amount of Super-Gas\textsuperscript{TM} wasted. Positive displacement piston pump has shown to be an improvement over the gear and diaphragm pumps regarding of working with a low viscosity and two-phase liquid, as well as handling a high output pressure requirement.

However, these prototypes do not have high volumetric efficiencies, which limit the fuel production. In order to improve these system it might be required require a new pump design. This pump should be able to work with low viscosity and two-phase fuel under high inlet and outlet pressure. Another improvement to be done is to place a telemetry system to measure the pressure inside the vehicle tank; therefore, the system will know the right pressure inside the tank.

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