Performance Comparison of the NEOgas System with a Conventional Compressor and two Booster Compressors

By NEOgas, Inc.

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Introduction

These tests were conducted by NEOgas China in June of 2007. The actual performance of a NEOgas station, booster station # 1, booster station #2 and one conventional compressor station were monitored. The sites are all commercial off-pipeline retail CNG stations operating at full capacity located in China.

Materials and methods

Data Acquisition:
The National Instrumentation (NI) USB-6008 data acquisition card (DAC) was used in this test. The NI USB-6008 provides connection to eight analog input (AI) channels, two analog output (AO) channels, 12 digital input and output channels and a 32-bit counter when using a full-speed USB interface.

The USB 6008 has one analog-to-digital converter (ADC). The multiplexer routes one AI channel at a time to a programmable-gain amplifier (PGA), that provides input gains. The PGA gains can be automatically calculated based on the voltage range measured.

Computer and Software:
A laptop computer with the windows XP operating system was used in this test... The National Instrumentation LabView program was used to develop a special software program that works with the NI DAC and stores data to the computer hard disk. This system can be used to record data for many hours or days depending on the sampling frequency and hard disk size.

In this test, the USB 6008 is connected to the laptop computer directly via a laptop USB port. The system records the data simultaneously from the input sensors at a user selected sampling frequency; the average value of certain readings can be stored on the hard disk. The recording parameters can be selected by the user.

Sensors:
Pressure sensor
Veris Industries PG 11 A V Pressure Transducer

- Pressure Range: 0-5000 psig
- Accuracy: ±0.25% BFSL
- Stainless Steel Construction
- 0-10 Vdc output voltage

This durable, stainless steel pressure sensor is ideal for CNG applications and is commonly used for aerospace and motorsport applications. It is a proven micromachined silicon sensor engineered for high quality and performance.

Power sensor

Veris Industries H8044-0300-2 3Ø Power Meter

- 3x300 Amp Split Core Current Transducers
- 4-20 ma output
- Accuracy ±1% of reading from 10-100% of CT rating

The design of this transducer reduces the number of installed components. Installation of this meter is simple; connect the three colored voltage leads and clamp on current transformers to the three power conductors to be monitored. The meter can automatically detect and compensate for phase reversal eliminating the concern of CT load orientation.

Temperature sensor

Veris Industries TB-D-B-0 strap-on sensor and AA-10-3 0-100 °C signal conditioner was used. This unit can be used in many refrigeration applications or it can be mounted on pipes for chilled or hot water temperature sensing.

Flow meters

For this test, the dispenser flow meters were used. The meters at these test sites had three types of signal output terminals (reference Micro Motion flow meter information for complete details). The spare 4-20 ma output signal was used to measure the direct output of gas flowing through that particular meter.

Data Monitoring:

Pressure, power consumption, gas flow rate, and temperature were recorded by using a laptop with the special designed software. Data was sampled at a frequency of 10 Hz. The sample data was averaged and stored to the laptop hard disk at one second intervals. The signals from all the sensors were monitored simultaneously and the recorded data was kept in a spreadsheet format for further analysis.

Sensor Calibration:

The pressure, power and temperature sensors are calibrated by the producers. The recorded voltage was directly converted into PSI, kW or degree C.

Because the CNG dispenser mass flow meter calibration may vary from meter to meter and station to station the flow rate was calibrated independently on site for each dispenser prior to recording data. Figure 1 show several refueling cycles from a typical meter calibration run. These refueling cycles are recorded automatically by using DAS and manually from the dispenser screen. The manually recorded value of each individual filling is then correlated directly with the total area of each filling curve to assure proper flow measurement calibration.

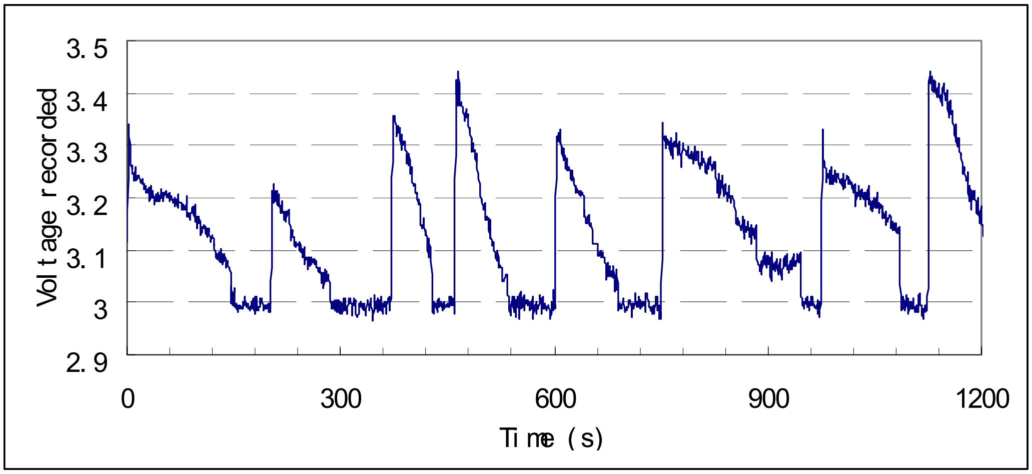

Figure 1. Raw data for calibration

Results and Discussion

1. Booster Station #1

Two booster compressor stations were measured. The performance specifications of Booster #1 are:

Compressor type:	Hydraulic Booster
Motor size:	22 kW
Minimum inlet pressure:	30 bar
Maximum inlet pressure:	200 bar
Output pressure:	250 bar

Figure 2 shows the relationship between the booster outlet pressure and the power consumption rate. Nine hours of recordings are shown in this figure. It is important to note how the power consumption tracks the outlet pressure.

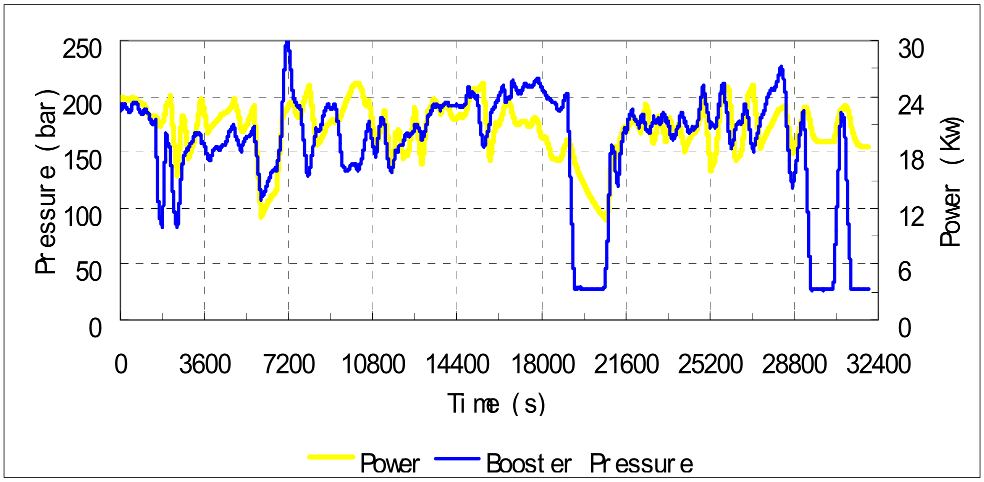

Figure 2 - Power and Booster Outlet Pressure for Booster #1

Refueling speed is an important performance parameter for a NGV stations. At this station, the CNG flow results of four hoses were recorded and added together. The total CNG flow is plotted with trailer and booster outlet pressure versus time as shown in figure 3.

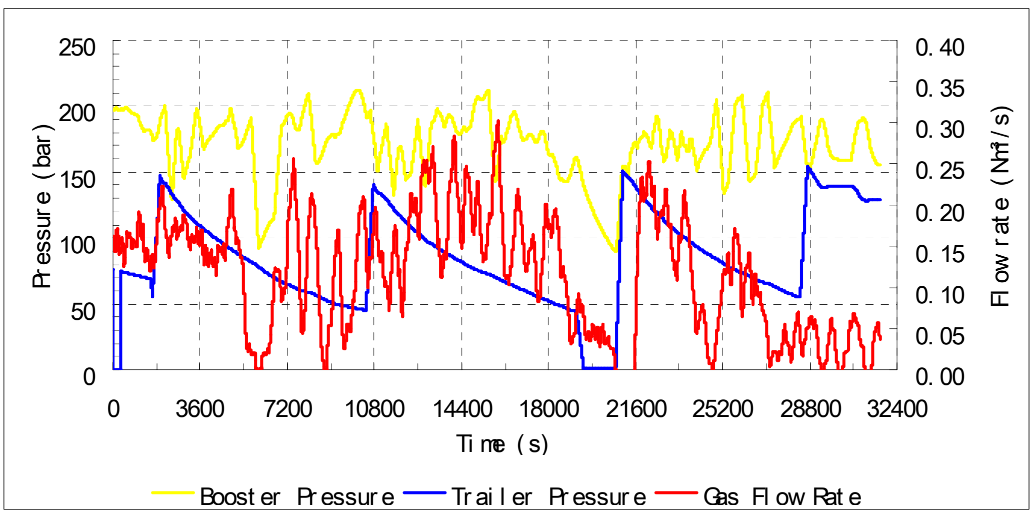

Figure 3 - Gas flow rate, Trailer Pressure and Booster Outlet Pressure for Booster #1

In this figure we can see the gas flow rate decreases as the trailer pressure decreases. It is very interesting to note that the trailer pressure upon arrival was ~ 150 bars. This is considered very low and results in an actual trailer carrying capacity significantly lower than the designed carrying capacity. This may be explained by a high filling temperature at the mother station (temperature was not recorded during this study) and because the mother station is ~80 km away from the daughter station.

The normalized power consumption, kWh consumed per Nm^3 of delivered gas, was calculated by taking the total power consumption and dividing by the total delivered gas. During the 9.3 hours of recording, 254.6 kWh of power was used to compress 5,385.3 Nm^3 of gas. This results in an hourly filling rate of 579Nm^3/h and a Normalized Power Consumption = 0.047 kWh/ Nm^3.

The residual pressure of the trailer can also be seen in figure 3. The trailer was disconnected with a residual CNG pressure of 50 to 70 bars even though the designed inlet pressure is 30 bars. This is likely due to the decline in unloading speed at low cylinder pressures. The trailer most likely is being swapped out early to maintain desired CNG station vehicle refueling speeds.

2. Booster Station #2

This station has the following performance specifications:

Inlet pressure:	5 - 230 bar
Outlet pressure:	250 bar
Capacity:	285 - 2360 Nm^3/hour
Motor:	30 kW

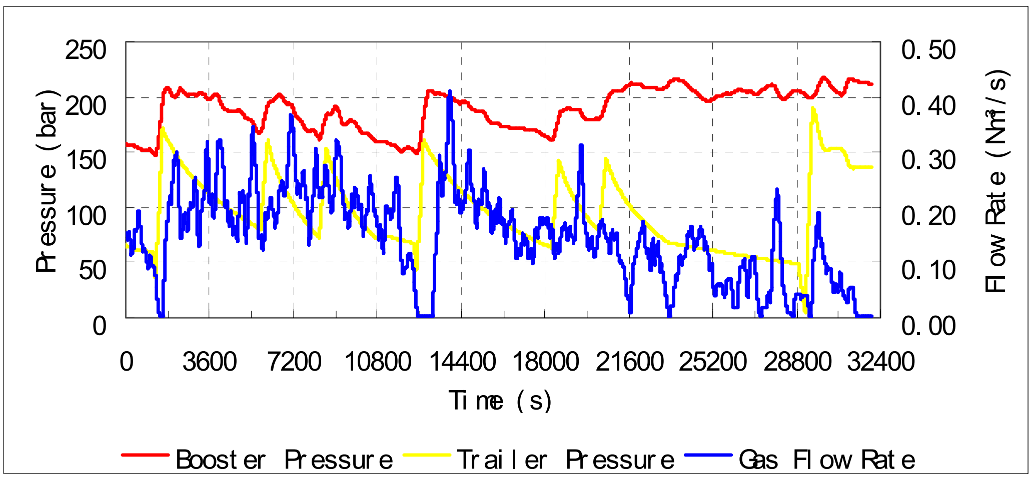

Figure 4 - Gas flow rate, Trailer Pressure and Booster Outlet Pressure for Booster #2

From figure 4, we see the gas flow rate is tracking the trailer pressure. The filling rate drops as the trailer pressure decreases. Trailers were swapped when residual gas pressure in the trailer reached 50 to 80 bar. This results in 23 to 36 percent of the initial gas being transported back to the compressor station; this is another important measure to understand when comparing off-pipeline CNG delivery systems.

In 24.3 hours of recording, a total of 1,3281Nm^3 of gas was compressed and delivered. The average hourly filling rate for Booster #2 was 546 Nm^3/hour. Note that the flow rate is dependent on the number of vehicles being refueled at the station on that day. A total of 689.4 kWh of power was used in during the recorded time; therefore Normalized Power Consumption = 0.052 kWh/Nm^3.

3. **Compressor Station**

The compressor station monitored had the following specifications:

Inlet pressure:	30 bar
Outlet pressure:	200 bar
Capacity:	1400 Nm^3/hour
Motor:	100 kW

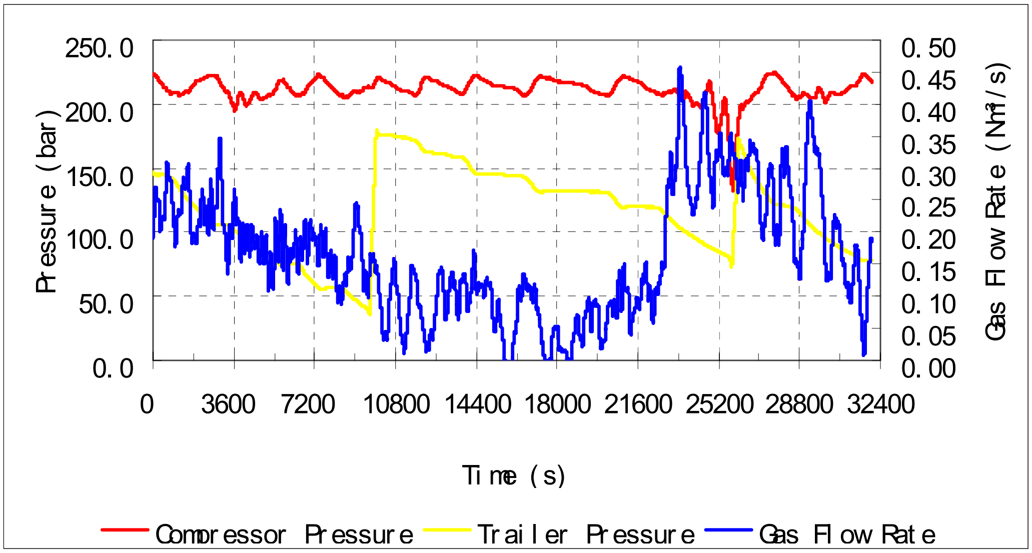

Figure 5 - Compressor station pressures and flow rate

The compressor outlet pressure was higher than the boosters analyzed, and the trailer was disconnected with the residual trailer pressure between 40 bars and 80 bars. The gas flow rate correlated to the trailer and compressor outlet pressure in figure 5. The flow rate does not appear to track trailer pressure as significantly as the booster compressors.

During 10 hours of operation, 5,997.4 Nm^3 of gas was dispensed and 277.7 kWh of power was used. The average delivery capacity of the station was 560 Nm^3/hour resulting in a Normalized Power Consumption = 0.046 kWh/Nm^3.

4. NEOgas Station

The NEOgas hydraulic power unit (HPU) has the following specification:

Residual trailer pressure:	10 bar
Outlet pressure:	200 bar
Capacity:	1000 Nm^3/hour
Motor:	30 kW

At this station two dispensers with 4 hoses were in operation. Data was collected for 9.7 hours with the first 5 hours of data shown in figure 6. The remainder of the data follows a similar pattern.

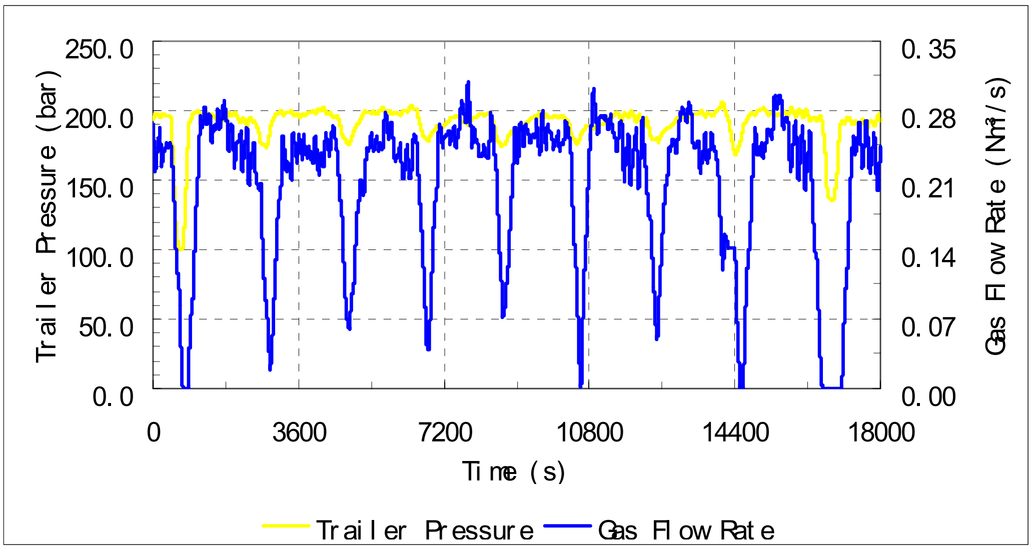

Figure 6 - NEOgas system performance

From this figure, it can be seen that the trailer pressure varies from 175 to 200 bar with the drop to ~175 bar occurring when the system transitions gas dispensing from one trailer cylinder to the next trailer cylinder. The delivery pressure reduces to 0 bar of pressure when swapping trailers. Since this is a single line dispensing system the gas flow rate is proportional to the trailer pressure, i.e. not high, medium and low storage pressures that 3 line systems experience, which results in a faster vehicle filling speed.

Because the pressure sensor was fixed on the main gas line from the HPU to the dispensers, the trailer initial and residual pressures were not recorded by the DAS. Typical HPU operation results in trailer residual pressure, i.e. following oil return back to the oil reservoir, of less than 10 bars or about 5% of total gas capacity.

7,005.8 Nm^3 of gas was dispensed and 270 kWh of power was used during the 9.7 hours of data recording This results in an average dispensing flow rate of 722 Nm^3 per hour, and a Normalized Power Consumption = 0.038 kWh

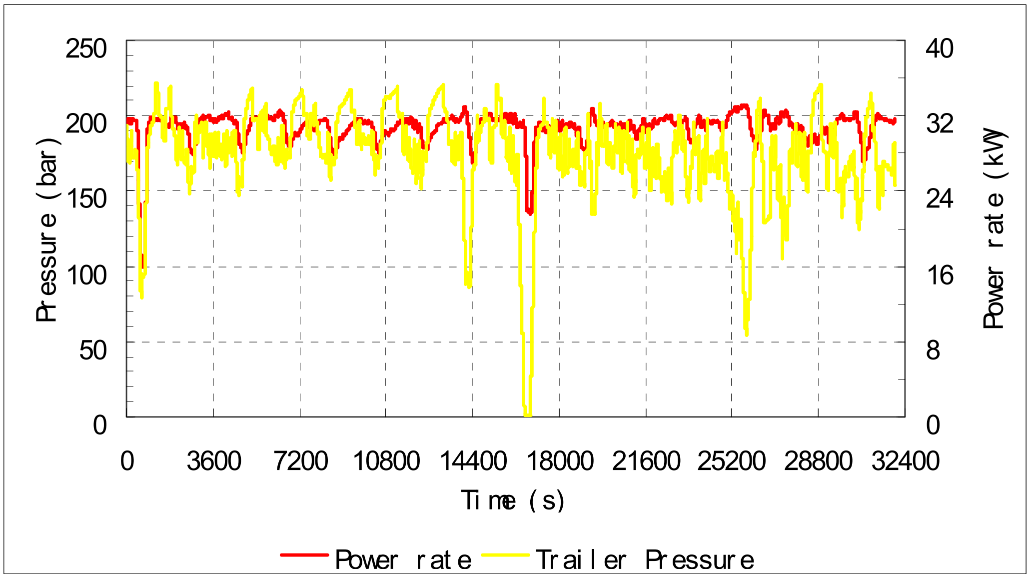

Figure 7 - Power rate and the trailer pressure

Figure 7 shows the relationship between the power requirement and the trailer pressure. The required power is proportional to the trailer pressure.

5. Gas Flow Rate and Refueling Curves

The actual filling speed of a NGV at a refueling station, in general, is a function of the pressure difference and flow restrictions between the filling pressure and the vehicle tank pressure. The filling speed is high when the pressure difference is large and decreases as the pressure differential declines. For a conventional daughter station, there is normally a three bank storage system. The priority panel controls the filling sequence among the three pressure storage cylinders. The NEOgas system does not require an additional gas storage system and uses a single input line gas dispenser. The trailer/filling pressure is kept relatively constant at 200 bars (can be changed by setting the PLC parameters) for the entire vehicle refueling operation.

Figure 8 compares the typical refueling patterns of an ordinary taxi for the NEOgas system and a three bank system. Both systems dispensed similar amount of gas (NEOgas 10.5Nm^3 and Booster #1 10.8Nm^3). The NEOgas system took 106 seconds and the 1st Booster system took 178 seconds to complete the taxi refueling process. The maximum filling rate of a NEOgas system is higher than that of the 1st Booster system with its three bank storage, because the actual filling pressure differential is high, resulting in greater gas flow rates during most of the refueling cycle. These results are demonstrated in figure 8.

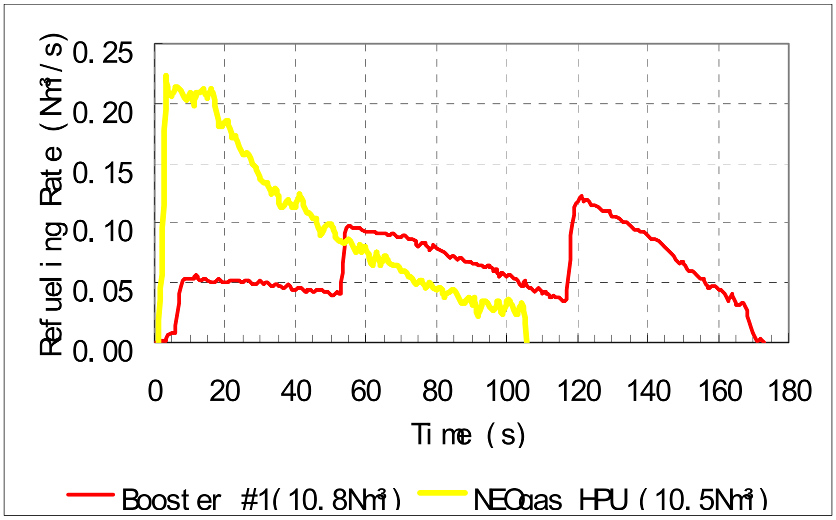

Figure 8 - Refueling Patterns

An attempt was made to compare filling times of the four systems tested; however, for similar dispensed volumes of fuel the fill times within each individual system varied significantly. The variation in fill time is a function of refueling station flow restrictions, variation in filling pressure and vehicle charge system flow restrictions. Since we did not measure the pressure at the fuel dispenser we could not determine the root cause of variation in vehicle fill time. Since vehicle filling time is such an important parameter in refueling station vehicle throughput and profitability, a means to compare these systems is needed. This was accomplished through a statistical comparison of the percentage of time each system spent at various flow rates.

Gas flow rate (Nm3/s) is defined as the volume of CNG dispensed per second. This rate is the indicator of the total refueling station gas flow (4 hoses) per second. In this section, the results of gas flow rate recordings for a period of 9 hours are analyzed statistically. During vehicle refueling, the recorded flow rate was ranked and the percentage of occurrence was plotted against the flow rate as shown in figure 9. A flow rate of 0.1 Nm^3/s means the station would work continuously for one hour to dispense 360 Nm^3 of gas. This is considered low for a commercial station. A gas flow rate of 0.2 Nm^3/s equals 720 $Nm^3/hour$ and may be considered a reasonable flow rates for a daughter station.

If 0.2 Nm^3/s is taken as the cut off point, it can be seen that 67% of the NEOgas flow rate values are more than 0.2 Nm^3/s, and only 11% of the 1st Booster Compressor's flow rate values are more than 0.2 Nm^3/s. This indicates that the NEOgas system provides a shorter refueling time per NGV.

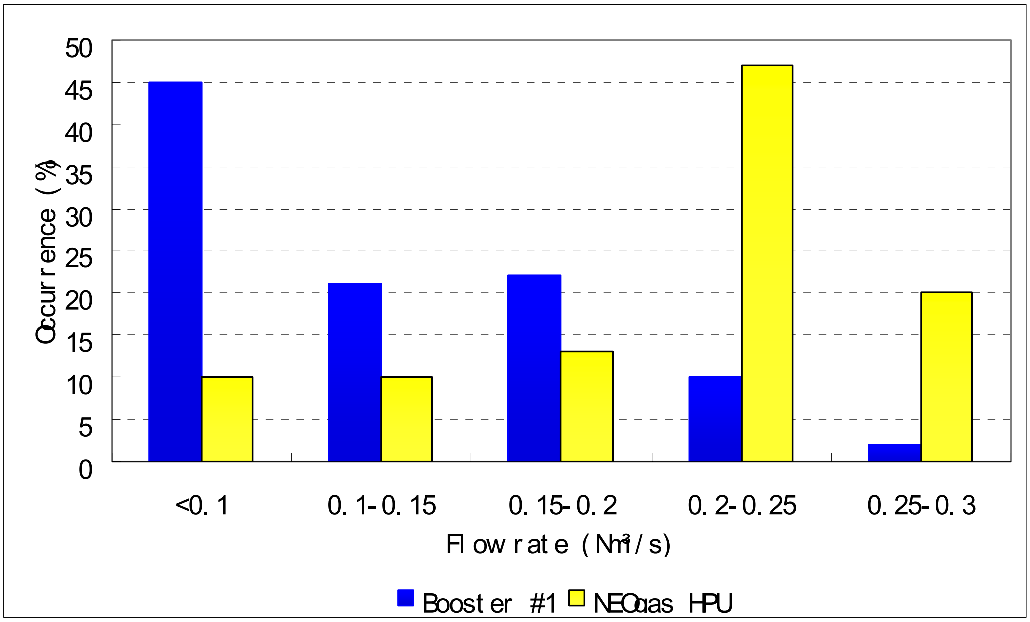

Figure 9 - Flow Rate Percentage of Occurrence

Performance Comparison and Conclusions

The primary difference between the NEOgas Hydraulic Power Unit and compressor technology is in the use of a non-compressible hydraulic fluid to maintain CNG refueling pressure. Pressurizing a non-compressible fluid is more energy efficient than compressing a compressible fluid. This enables the NEOgas system to provide lower power consumption, eliminate three bank storage systems, provide shorter vehicle fill times (result of single high pressure refueling system versus three pressure refueling systems) and dispense more of the transported CNG (the system is not affected by low trailer inlet pressures). These results are demonstrated in Table 1 where the four systems are compared.

Refueling Station System	Max Filling Pressure (bar)	Average CNG Flow Rate (Nm^3/h)	Normalized Power Consumption (kWh/Nm^3)	Residual Trailer Pressure (bar)	% of Flow Rate >$0.2Nm^3/s$
NEOgas HPU	200	722	0.038	10 (estimated)	67%
Booster #1	210	579	0.047	50-70	11%
Booster #2	220	546	0.052	50-75	26%
Compressor	225	560	0.046	40-80	34%

Table 1. Performance parameters of the stations monitored.

Refueling speed is indicated by the percentage of time a stations flow rates are greater than 0.2 Nm^3/s. The NEOgas system spends 67% of its refueling time at this level of flow. Power consumption per Nm^3 of gas dispensed is also shown in the table. This is an important parameter for stations because it is an indication of the operating cost of the station. The NEOgas system consumed 0.038 kWh of power per Nm^3, compared to the other systems which consume at least 21% more power per Nm^3 of gas delivered.

The performances of these four stations were measured under Chinese operating conditions. All stations were operated at full capacity. For much of the time, NGV's were waiting in queue for refueling. It is believed that the results being compared herein are indicative of similar operating conditions.