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Analysis of Internal Power Consumption for the 5 kW HT-PEFC System by ASPEN Plus

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Abstract

We analyzed the internal power consumption with mechanical efficiency of subcomponents such as pumps and compressors in the 5 kW HT-PEFC based APU system by Aspen plus. The HT-PEFC based APU system consumed 784 W for internal device with 75% of pump efficiency and 90% of compressor mechanical efficiency. Power demand for blower to stack is 40% of total power demand for internal devices.

Keywords: 5 kW HT-PEFC; APU; Pump; Compressor; Aspen plus

Introduction

Auxiliary power unit (APU) could save the fuel consumption and prolong the engine life expectancy by generation of electricity without engine idling. U.S Army reported that 1 set of APU could save 74 gallons of fuel for Abrams tank on the battle field per battle day [1]. Abrams engine consumed 17 gal/hr, with tactical idle at 1250 rpm, however Abrams APU consumed only 1.5 gal/hr [1]. Fuel cells based APU is promising device for military applications due to its silence. It could enable “silent watch” to military vehicles in the battle field. Polymer electrolyte fuel cell (PEFC) is promising for APU system due to its short start time. PEFC operated at low temperature could provide shorter start time compared with Solid oxide fuel cell (SOFC). However, PEFC has a problem of CO poisoning. High-temperature PEFC operated at 160°C is a candidate for solution due to its increased CO tolerance. The increased CO tolerance and short start time make HT-PEFC as an attractive candidate for fuel cells based APU system. The storage and transportation of hydrogen are difficult matters due to its technical barrier. On board fuel processor for produce the hydrogen from propellants such as diesel and gasoline could remove the problem of hydrogen storage and transport. Many research groups focused on the auto thermal reforming (ATR) method as an on-board hydrogen production method [2-7]. Consequently, ATR integrated with PEFC system is also investigated as an APU system [8-10]. ATR integrated HT-PEFC system need many subcomponents such as pump and compressor for fed water, air, and fuel to ATR, stack, and CAB. Samson reported 365 W needed for internal power for ATR integrated 5 kW HT-PEFC system [11]. Suthida Authayanun also reported that required power for pump and compressor must be calculate for system efficiency [12]. Zhao reported that maximum motor isentropic efficiency of centrifugal compressor was 70% [13]. The experimental result about effect of air compressor on PEMFC was also reported [14,15]. In this study, we focused on produced power and internal power consumption of the ATR integrated 5 kW HT-PEFC system with diesel. Power demands for subcomponents such as pump and compressor with efficiency were investigated by Aspen plus software.

Design and Simulation of 5 kW HT-PEFC based APU System

Design of 5 kW HT-PEFC based APU system

In this system, ATR fuel processor, Water Gas Shift (WGS) reactor, HT-PEFC stack, and catalytic burner (CAB) are major sub-system. In addition, subcomponents such as pump, compressor, and stack cooling system also exist in the system. Figure 1 shows a simplified flow sheet of the ATR integrated 5 kW HT-PEFC system. In the system, super-heated steam prepared from water and air in the heat exchanger, and reformate prepared from super-heated steam, diesel fuel, and air in the mixing chamber. Reformate fed to the High-temperature shift stage (HTS) of WGS. Reformate was cool downed by water quenching at Low-temperature shift stage (LTS). The CO level could reduce to 1 vol.% at the end of WGS. Reformate from the LTS fed to anode, and compressed air fed to cathode of HT-PEFC. An anode off gas fed to CAB, and completely removed in the CAB.

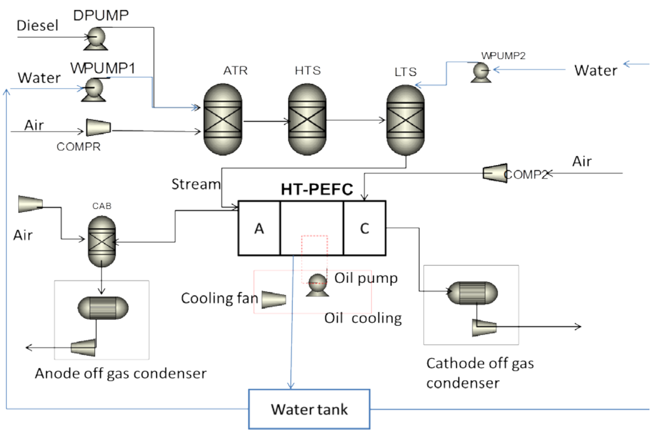

Figure 1: Simplified flow sheet of the 5 kW HT-PEFC system.

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Modeling and simulation

In this study, an aspen plus simulation model for 5 kW HT-PEFC system which already designed by Remzi [3,11] was used. We modified the interface for that clearly change the efficiency of subcomponents and distinguish results about power demand for pump and compressor. Specifically, we changed the flow sheeting options-calculator-compressor and pump by using set-parameter. In addition, we change the isentropic efficiency of compressor to 0.5 which based on the research report about compressor [10]. Table 1 shows simulation parameters for the ATR integrated HT-PEFC system. The diesel fuel calculated as a $C_{17}H_{36,}$ and the power class was designed for 5 kW. The temperature and humidity of ambient air were set a 25°C and 60%. ATR, WGS, Stack, CAB were modeled as an RGibbs reactor in the model pallet of Aspen plus. The water-to-carbon ratio (H_2O/C) and oxygen-to-carbon ratio (O_2/C) in ATR were set a 1.90 and a 0.47 based on experimental data. The temperature of steam at an inlet of ATR was set a 420°C. The stack has 70 cells and each cell has an active area of 320.13 cm^2. The 83% of fed hydrogen utilized in the stack, and cathode air ratio was set a 2. The current density was calculated by Equation 1.

$$J = \frac{H_{2\,Flow\ rate} \times 2 \times Faraday\ const}{N_{cell} \times A_{active}} \qquad (1)$$

Results

Performance of ATR integrated 5 kW HT-PEFC system

Table 2 shows simulated result for stream in each stage on the system. The mole fraction of hydrogen after ATR process was 0.297293, and increased to 0.336889 from WGS process. The stream which contain 0.336889 mole fraction of hydrogen fed to anode of stack with a 0.698968 kmol/hr of flow rate. In addition, the mole fraction of CO was 0.071443 after ATR. However it decreased to 0.007633 after 2-stage of WGS, and fed to the anode of stack. The temperature of streams after ATR was 362.6°C, 413.9°C at an outlet of HTS, 319.4°C at an outlet of LTS, and stream was fed to anode at 160 °C. Table 3 shows simulated result related with power on the system. The hydrogen flow rate on the system was a 0.19544 kmol/hr. The HT-PEFC stack exhibited a 477.539 mV of voltage and a 399.098 mA/cm^2 of current density. The net produced power was a 4250.95 W with 1.62659 kg/hr of fuel demand. Further, internal consumed power was a 749.05 W at a 0.75 of pump efficiency, a 0.95 of compressor mechanical efficiency.

Parameter	Value	Unit
Fuel	Diesel ($C_{17}H_{36}$)	
Fuel cell power	5	kW
Number of cells	70	
Active area of each cell	320.13	cm^2
Hydrogen utilization in the stack	83	%
H_2O/C ratio in ATR	1.90	
O_2/C ratio in ATR	0.47	
Steam temperature at the inlet of ATR mixing chamber	420	°C
Temperature of reformate at the inlet of LTS after water quenching	300	°C
Steam temperature after CAB heat exchanger	160	°C
Cathode air ratio	2	
Inlet temperature of heat exchange medium for stack cooling	160	°C
Air ratio in the CAB	1.05	
Pressure drop(ATR/WGS/Anode/Cathode/CAB)	70/40/40/40/40	
Condensation temperature	45	°C
Ambient air temperature	25	°C
Ambient air relative humidity	60	%

Table 1: Simulation parameters for the 5 kW HT-PEFC based APU system.

Mole Fraction	ATR OUT	HTS OUT	LTS OUT	ANODE IN	ANODE OUT
CO_2	0.10209	0.14743	0.154504	0.154504	0.2144755
CO	0.071443	0.026103	0.007633	0.007633	0.0105957
H_2	0.297293	0.342633	0.336889	0.336889	0.0795009
CH_4	0.002663	0.002663	0.002488	0.002488	0.0034539
H_2O	0.226221	0.180881	0.217914	0.217914	0.3024979
O_2	8.39E-23	0	0	0	0
N_2	0.296742	0.296742	0.277256	0.277256	0.3848727
AR	0.003549	0.003549	0.003316	0.003316	0.00460329
Total Flow (kmol/hr)	6.53E-01	0.653069	0.698968	0.698968	0.503524
Total Flow (kg/hr)	12.84332	12.84332	13.6702	13.6702	13.27621
Temperature (°C)	362.5882	413.8837	319.3974	160	160
Pressure (bar)	1.25255	1.23295	1.23295	1.1382	1.1382

Table 2: Simulation results for streams in the ATR integrated 5 kW HT-PEFC system.

Parameter	Value	Unit
H_2 Flow rate	0.195444	kmol/hr
Current Density	399.098	mA/cm^2
Voltage	477.539	mV
Produced Power	5000	W
Internal consumed Power	749.05	W
Net Produced Power	4250.95	W
Fuel Demand	1.62659	kg/hr

Table 3: Simulation results for power in the ATR integrated 5 kW HT-PEFC system.

Effect of pump efficiency for internal power demand

In general, pump means devices used to transport liquids, gases, and slurries. The term pump in Aspen Plus was used to liquid handling device. The pump provides certain pressure at a certain flow rate to stream in the model. Required power for pump in Aspen plus model was calculated by Equation 2.

$$Required\ Power = \frac{Fluid\ Power\,(W)}{Pump\ efficiency} \qquad (2)$$

Consequently, the fluid power was calculated by Equation 3, and the pressure change means pressure difference between the outlet and inlet of pump.

$$Fluid\ Power = \Delta Pressure \times Flow\ rate\ of\ fluid \qquad (3)$$

In brief, we can calculate the power demand for pump in Aspen plus model by Equation 4.

$$P = \frac{\Delta p \times Q}{\eta} \qquad (4)$$

In this Equation 4, P is the required power for pump, Δp is the change in the total pressure of stream between the inlet and outlet of pump (Pa), and Q is the volume flow rate of the fluid (m^3/s). We calculated power demand in the 5 kW HT-PEFC system with fuel process by Aspen plus simulation based on Equation 3. Table 4 clearly shows simulated results of required power for pump in the HT-PEFC system. Diesel and water pump for ATR, water pump for LTS, oil pump for stack cooler with a 0.75 of pump efficiency needed power of 3.89, 6.03, 1.26, and 49.67 W, respectively. The power demand result for pumps is negligible due to its required power is too small. However, power demand for pump drastically increased when the efficiency of

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Parameters	Unit	ATR		LTS	Oil cooling
		Diesel	Water	Water	Oil
Pressure inlet	MPa	0.1013	0.10264	0.10264	0.1013
Pressure outlet	MPa	5	4	4	0.2
Pressure change	MPa	4.8987	3.89736	3.89	0.0987
Volumetric flow rate	m^2/s	5.9512E-7	1.16061E-6	2.43459E-7	3.7745E-4
Fluid Power	W	2.91	4.52	0.94	37.25
Pump efficiency	-	0.75	0.75	0.75	0.75
Required Power	W	3.88	6.03	1.26	49.67

Table 4: Simulation results for power demand of pumps in the ATR integrated 5 kW HT-PEFC system.

Efficiency	Power demand(W)				
	ATR		Oil cooler	WGS	Total
	Diesel pump	Water pump	Oil pump	Water pump	Pumps
0.1	29.31	45.67	372.54	16.00	463.53
0.2	14.71	22.73	186.27	8.081	231.80
0.3	9.82	15.06	124.18	5.66	154.73
0.4	7.33	11.40	93.13	3.38	115.26
0.5	5.82	9.04	74.50	3.16	92.55
0.6	4.85	7.53	62.09	2.64	77.12
0.7	4.17	6.49	53.22	1.93	65.82
0.8	3.64	5.65	46.56	1.69	57.55
0.9	3.28	5.06	41.39	1.68	51.43
1	2.94	4.52	37.25	1.62	46.34

Table 5: Simulation results for net power and internal power consumption in the ATR integrated 5 kW HT-PEFC system.

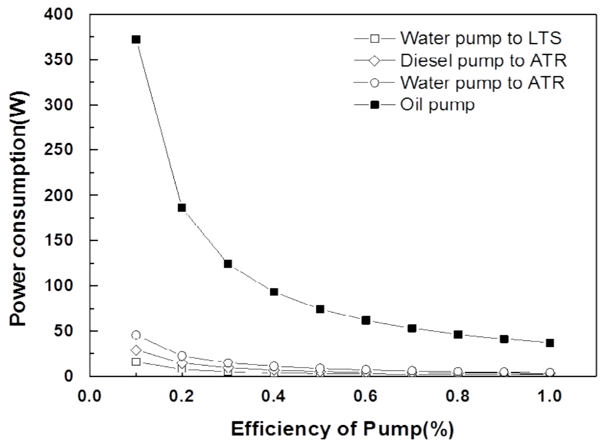

Figure 2: Power consumption of pump with mechanical efficiency in the ATR integrated 5kW HT-PEFC systems.

oil pump downed below the 0.5, as shown by Table 5. Table 5 shows simulation result for power demand of pump with efficiency in the system. Power demand for oil pump was increased to 372 W at a 0.1 of pump efficiency as shown Figure 2. Consequently, the efficiency of oil pump must be considered at an initial design of the system.

Effect of compressor mechanical efficiency for internal power demand

Compressor is the device used to gas compression. Compression process could increase to temperature and change the volume in gas. Centrifugal compressors have two type models. The one is one stage compressor that means fan, another one is multi stage compressor that means blower and compressor. There are 4 types of compressor in the 5 kW HT-PEFC system that are air compressor to the ATR, blower to the stack, blower to the CAB, and air cooling fan. We can calculate the required power for compressor devices by Equation 5.

$$P = \frac{\Delta H}{\eta_m} \tag{5}$$

In the Equation 5, P is the required power for compressor, ΔH is the enthalpy change between the inlet and outlet in the compressor, and η_m is mechanical efficiency of compressor. Table 6 shows calculated power demand for compressor at a 0.9 of mechanical efficiency in the 5 kW HT-PEFC system. The power demand for compressors was high compared with that of pumps. Required power for compressor to ATR was a 103.171 W, the blower to stack was a 313.405 W, the blower to CAB was a 36.227 W, and the air cooling fan was a 93.877 W at a 0.9 of compressor mechanical efficiency. Figure 3 shows the change of power consumption for compressor with mechanical efficiency in the system. The power demand of the blower for CAB was similar with efficiency change; however the power demand of the air cooling fan and the blower for stack was significantly increase with decrease of efficiency. Table 7 shows simulated result about internal power consumption with mechanical efficiency for compressor. In this simulation, the power demand for total pumps was set as a 65.8243 W which means total power demand for pumps with 0.75 of pump efficiency. The internal power consumption of the 5 kW HT-PEFC system was a 783.3675 W with 0.75 of pump efficiency and a 0.9 of compressor mechanical efficiency. The total internal power demand was increased to 1681.421 W when compressor mechanical efficiency was downed to 0.4. The net power produced in the system was a 4216.132 W at a 0.75 of pump efficiency and a 0.9 of compressor mechanical efficiency. However, the net power in the system decreased to 3318.579 W with 0.4 of

	Enthalpy In	Enthalpy out	Enthalpy change	Required power (W)
Compressor for ATR	-331.787559	-238.933036	92.854523	103.17
Blower to stack	-1247.5394	-965.474859	282.064541	313.40
Blower to CAB	-175.35893	-142.754934	32.603996	36.22
Air cooling fan	-6429.93426	-6345.44439	84.48987	93.87

Table 6: Calculated power demand for compressor at a 0.9 of mechanical efficiency in the ATR integrated 5 kW HT-PEFC system.

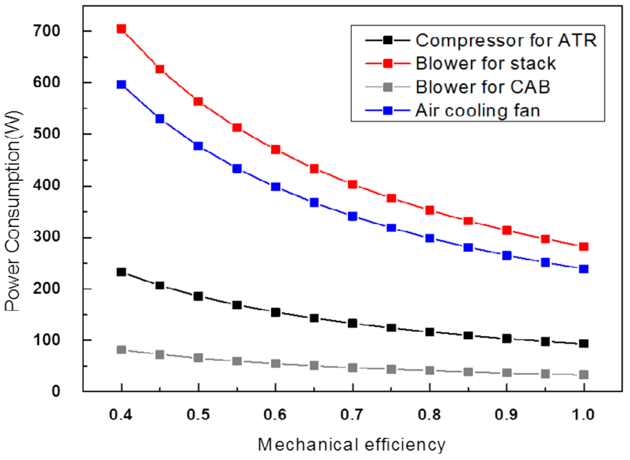

Figure 3: Power consumption of compressor with mechanical efficiency in the ATR integrated 5 kW HT-PEFC systems.

Efficiency	Power demand for Components (W)					Internal Power Demand(W)
	pump	Compressor to ATR	Blower to stack	Blower to CAB	Air cooling fan	
1	65.82	92.85	282.06	32.60	238.71	712.06
0.95	65.82	97.74	296.91	34.31	251.27	746.07
0.9	65.82	103.17	313.40	36.22	265.23	783.86
0.85	65.82	109.24	331.84	38.35	280.84	826.10
0.8	65.82	116.07	352.58	40.75	298.394	873.62
0.75	65.82	123.81	376.08	43.47	318.28	927.47
0.7	65.82	132.65	402.94	46.57	341.02	989.02
0.65	65.82	142.85	433.94	50.15	367.25	1060.03
0.6	65.82	154.76	470.10	54.33	397.85	1142.88
0.55	65.82	168.83	512.84	59.27	434.02	1240.80
0.5	65.82	185.71	564.12	65.20	477.43	1358.30
0.45	65.82	206.34	626.81	72.45	530.47	1501.91
0.4	65.82	232.14	705.16	81.50	596.78	1681.42

Table 7: Simulation result for internal power consumption of the ATR integrated 5kW HT-PEFC systems.

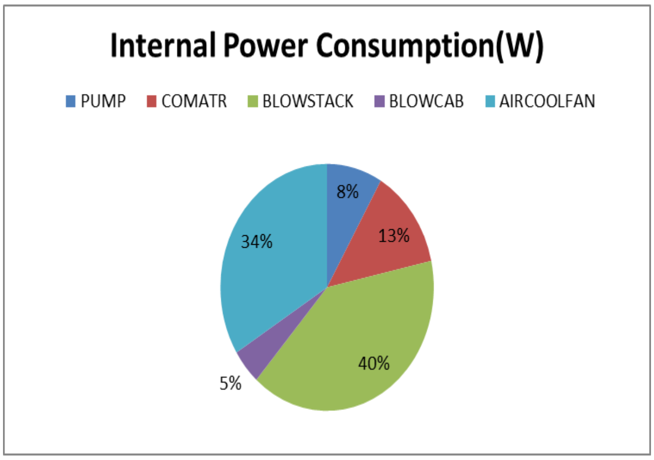

Figure 4: Diagram for internal power consumption of subcomponents in the ATR integrated 5kW HT-PEFC systems.

compressor mechanical efficiency. Power demands for blower to stack and air cooling fan was 74% of the total internal power consumption as shown Figure 4.

Conclusions

In this study, we analyzed internal power demand for pump and compressor in the 5 kW HT-PEFC system by aspen plus software. Internal power consumptions must considered when we design the power class of ATR integrated PEFC system. Further, the efficiency of the blower to stack and air cooling fan are important factor for internal power consumption of the ATR integrated HT- PEFC system.

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