

Testing Results of the Cross-Contamination Test of Seibu-Giken "HI-PANEX-ION" Enthalpy Wheel

Testing Results on the Cross-Contamination via the Seibu-Giken “HI-PANEX-Ion” Enthalpy Wheel

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INTRODUCTION

Ventilation is also necessary technology for the air-handling process to improve indoor air quality. However, simple ventilation increases the air-conditioning load in exchange for discharging the indoor CO₂ and some kinds of air pollutants. In this regards, enthalpy exchange technique plays important role in achieving a higher indoor air quality with lower energy consumption. Enthalpy exchanger works between the fresh air entering the building and the exhaust air leaving the building for example. Since latent heat (humidity) as well as sensible heat can be recovered in exchange, it has a high energy-saving effect. Its market scale is growing with increasing of the recognition of saving-energy in the air-conditioning systems, and different types of products have been manufactured in various countries. Wheel and plate-fin types of the enthalpy exchanger are the commonly used energy recovery devices. Generally, wheel type tends to show higher heat exchange efficiencies of both latent and sensible since the rotation of the wheel can increase the surface area of the wheel contacted with air stream.

Desiccant materials such as silica gel and molecular sieves are used so as to give it a latent heat exchanging function. However, this important function has become the cause of cross-contamination because the substances with an offensive odor are also adsorbed in the desiccant. Cross-contamination occurs when returned indoor air contaminants are transferred from the exhaust stream to the fresh outside air stream during the heat and moisture exchanges. This contamination in an enthalpy wheel are due to air leakage through the seals around the wheel, exhaust air contained in gaps of the honeycomb being transferred to the fresh air side by wheel rotation and adsorption/desorption of contaminants onto/from the wheel. The first and second one could be mechanically prevented, but the last one should be solved by considering the relation between humidity, contaminants and desiccant materials.

In other words, higher efficiencies of heat and humidity exchange with no cross-contamination are features requested for a functionally favorable enthalpy wheel. For the sake of achieving these features, Seibu Giken Co. Ltd. has been developed an enthalpy wheel using ion exchange resin as a desiccant and commercialized under a name “HI-PANEX-Ion Enthalpy Wheel”. In this study, the odor transfer tests for typical contaminants such as ammonia were carried out using this novel enthalpy wheel and compared with those of the 3A molecular sieve enthalpy wheel purchased for the test.

HI-PANEX-Ion Enthalpy Wheel

Special feature of the HI-PANEX-Ion enthalpy wheel is employment of an ion exchange resin as a desiccant (Okano et al., 2001). At first, fine particles of a strongly acidic cation exchange resin, which is linear polymers of styrene cross-linked by divinyl benzene containing sulfonic acid radicals (SO₃H) and sodium ions (Na⁺) as counter ion, were sprayed and adhered rigidly to aluminum sheet coated with a kind of binder. Then, it was treated with anti-bacterial and anti-mold coating as shown in Figure 1. Finally, the aluminum sheet was corrugated and made into a honeycomb wheel.

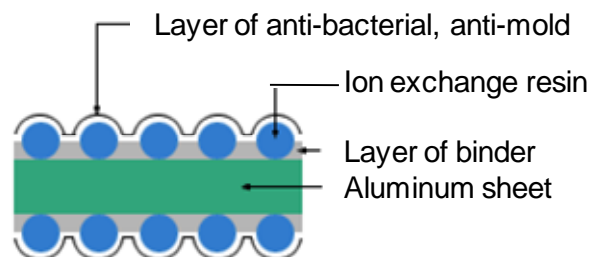


Figure 1 A sectional drawing of the wheel element of HI-PANEX-Ion Energy Exchanger

According to the conference paper (Okano et. al., 2001), incorporation of water into ion exchange resin is caused by hydration power and osmosis of ions, and it has been reported that ion exchange resin has a desiccative characteristic intermediate between silica gel type A and silica gel type B. It has been also confirmed that water vapor can be easily adsorbed and desorbed by relative humidity changes by the above-mentioned ion exchange resin.

EXPERIMENTAL

All experiments and calculations were strictly conducted by ANSI/ASHRAE approved Standard 84-2008 “Method of Testing Air-to-Air Heat/Energy Exchangers” and ARI 1060-2005 “Performance Rating of Air-To-Air Heat Exchangers for Energy Recovery Ventilation Heat Equipment”. Experimental set-up and experimental procedure were carefully considered so as to satisfy the requirements given in the above mentioned rules.

Experimental set-up

A schematic diagram and photograph of the experimental set-up are shown in Figure 2. As indicated in Table 1, Seibu Giken HI-PANEX-Ion enthalpy wheel and the purchased 3A molecular sieve enthalpy wheel were provided for the cross-contamination test. In order to adjust the both flow rates and pressure difference between SA and RA to the values recommended in the rules, three inverter-speed control blowers were used. While the blower C was almost constantly sending outside fresh air to the supply side of the enthalpy wheel, blowers B for sending the return air and C for withdrawing the exhaust air were controlled severely to produce a defined pressure difference $\Delta P(SA-RA)$ in cooperation with each other. For all tests, both RA and SA nominal face velocities were 3 m/s. Experimental conditions were summarized in Table 2. Also, contaminants used for the cross-contamination test are listed in Table 3.

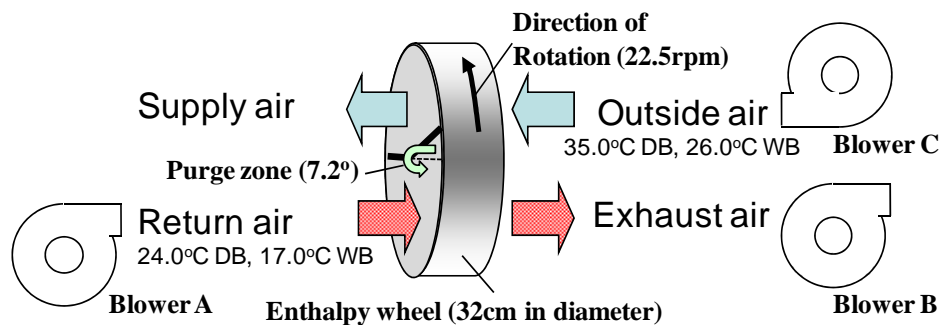


Figure 2 Schematic diagram and photograph of the experimental set-up

Table 1 Enthalpy wheels tested in this study and their dimensions

Seibu Giken HI-PANEX-Ion enthalpy wheel	32cm in diameter, 20cm in height
3A molecular sieve enthalpy wheel	32cm in diameter, 28cm in height

Table 2 Experimental condition

Outside air condition	35.0 °C Dry-bulb, 26.0 °C Wet-bulb
Return air condition	24.0 °C Dry-bulb, 17.0 °C Wet-bulb
Purge zone angle	7.2 °
Rotation speed of wheel	22.5 rpm
Superficial velocity of air	3 m/s
RA/SA air flow ratio	1
Pressure difference SA-RA	0 or 250 Pa

Table 3 Tested contaminants in this study

Contaminant	Chemical Formula	Molecular Weight
Ammonia	NH ₃	17.03
Carbon Dioxide	CO ₂	44.01
Formaldehyde	HCHO	30.03
Propan-2-ol (IPA)	(CH ₃) ₂ CHOH	60.10
4-methyl-2-pentanone (MIBK)	C ₄ H ₉ COCH ₃	100.16
p-Xylene	(CH ₃) ₂ C ₆ H ₄	106.17
Propane	C ₃ H ₈	44.10

Experimental procedure

Return and outside air conditions, their flow rates and other operating conditions were carefully controlled to the values indicated in Table 2. Air condition, namely humidity and temperature were measured by dew point meter (General Eastern HYGRO M4 + 1311DR-SR) and Type-T thermocouples, respectively. Also, four air flow meters (Wetmaster AE-100D; an annubar type Pitot tube) were equipped with the experimental set-up to measure the air flow amounts of OA, SA, RA and EA. Pressures difference between SA and RA was measured by a digital manometer (Nagano Keiki GC62) and sampling ports for this pressure difference were located at places close to the SA outlet and RA inlet of the wheel.

After the experimental condition and the enthalpy exchanger itself had reached to a steady state, one of the contaminants listed in table 3 was injected into the return air. Here, concentrations of the tested contaminants were controlled by the following different ways. Injection rate of two gaseous contaminants, carbon dioxide and propane, were kept at constant values by using mass flow controller (Kofloc Type 8300-MC). Ammonia was injected by aeration. Air stream was supplied to ammonia water at a controlled flow rate and then ammonia rich air could be introduced into the return air duct. The rest of contaminants, liquid compounds, were supplied to a glass Petri-dish in the return air duct at a controlled flow rate using a tube pump and then vaporized contaminants could be added to the return air. In the event that speed of the vaporization was not high enough to provide a target concentration, the glass Petri-dish in the return air duct was heated by a hot plate.

At least 20 minutes after the all above mentioned preparations had been completed, air sampling procedure was started. Air suction from the four ducts were carried out at the same time by using gas sampling bags and a gastight syringe depending on the absolute pressure of the air streams. This process was repeated at least two times for each contaminant considering not only the accuracy of the detected concentration but also mass-balance.

Detection of the contaminants

Gas chromatography and gas detector tubes were employed to detect the contaminants. Carbon dioxide was detected by using gas chromatograph (Yanaco GC2800 FID + Porapak T Column) connected with methane converter. In the catalytic reaction, carbon dioxide was completely converted to methane and then GC-FID could detect methane as carbon dioxide. Concentration of propane was also measured by the same gas chromatograph (Yanaco GC2800 FID + Porapak T Column), however methane converter was not equipped in this case. Gas detector tubes (Komyo Rikagaku Kogyo) were used for ammonia and formaldehyde. Gas detector tube No.105SD was applied to ammonia and its measuring range was 0.2 - 20 ppm. For formaldehyde, No. 171SC gas detector tube was used and its measuring range was 0.05 - 4 ppm. The remaining contaminants, Propan-2-ol, 4-methyl-2-pentanone and p-Xylene, were detected by using GC-FID (Shimadzu GC-2014 + DB-WAX column).

TESTING RESULTS

Enthalpy exchange efficiency

Enthalpy exchange efficiencies of the both wheel were investigated and compared. The testing method was in accordance with ASHRAE Standard 84 -2008. Heat exchange efficiency was defined as follows.

$$\text{Enthalpy exchange efficiency} = (I_{SA} - I_{OA}) / (I_{RA} - I_{OA}) \times 100 \text{ [\%]} \quad (1)$$

where I_{SA} = supply air enthalpy, I_{OA} = outdoor air enthalpy, I_{RA} = return air enthalpy.

Enthalpy exchange efficiencies are shown in Table 4. Paying attention to the difference in the height of the wheels, it can be concluded that the HI-PANEX-Ion wheel has almost the same enthalpy exchange efficiency as that of the purchased 3A molecular sieve enthalpy wheel.

Table 4 Enthalpy exchange efficiency [%]

Enthalpy wheel	$\Delta P(\text{SA-RA})=0\text{Pa}$	$\Delta P(\text{SA-RA})=250\text{Pa}$
Seibu Giken HI-PANEX-Ion (20cm in height)	78.1	76.8
3A molecular sieve (28cm in height)	80.2	78.2

Cross-contamination ratio

Cross-contamination ratio was calculated by the following equation.

$$\text{Cross-contamination ratio} = (C_{SA} - C_{OA}) / (C_{RA} - C_{OA}) \times 100 \text{ [\%]} \quad (2)$$

where C_{SA} = Concentration of contaminant in the supply air [ppm], C_{OA} = Concentration of contaminant in the outdoor air [ppm], and C_{RA} = Concentration of contaminant in the return air [ppm]. From a viewpoint of the mass balance, weight flow rates of each air streams may be considered into the above equation if the accurate cross-contamination ratio is requested.

Test results are shown in Tables 5 – 11 for the contaminants listed in Table 3. Error in the mass balance of each respective contaminant is also indicated at the right side column in the corresponding table. It is calculated by Equation (3) and this follows the ASHRAE Standard 84-2008.

$$\text{Error in the mass balance of contaminant} = \frac{\dot{m}_{OA} \cdot C_{OA}^* - \dot{m}_{SA} \cdot C_{SA}^* + \dot{m}_{RA} \cdot C_{RA}^* - \dot{m}_{EA} \cdot C_{EA}^*}{|\dot{m}_{OA} \cdot C_{OA}^* - \dot{m}_{RA} \cdot C_{RA}^*|} \quad (3)$$

where \dot{m}_{OA} = mass flow rate of the outside air [kg/s], \dot{m}_{SA} = mass flow rate of the supply air [kg/s], \dot{m}_{RA} = mass flow rate of the return air [kg/s], \dot{m}_{EA} = mass flow rate of the exhaust air [kg/s], C_{OA}^* = Concentration of contaminant in the outside air [mol/kg] or [g/kg], C_{SA}^* = Concentration of contaminant in the supply air [mol/kg] or [g/kg], C_{RA}^* = Concentration of contaminant in the return air [mol/kg] or [g/kg], C_{EA}^* = Concentration of contaminant in the exhaust air [mol/kg] or [g/kg]. ASHRAE Standard 84-2008 requests that the cross-contamination test should be accomplished with maximum error in the mass balance of contaminant of 0.05, holding errors in mass balance of air flows and heat balances within requested values.

DISCUSSION

Results of each cross-contamination test individually indicated in Tables 5-11 are averaged and summarized in Table 12. First of all, it can be recognized that some values of the cross-contamination ratios listed in these are larger than those indicated in the manufacturer's own test report (Okano et. al., 2001). The reasons for the difference in the results between this test and the manufacturer's one are mainly considered to be those as follows.

- ✓ In this test, superficial velocities of the supply and the return air were kept at 3 m/s for the each cross sectional area, but those in the previous report were 4.5 m/s.
- ✓ Rotation speed of the wheel in this report, 22.5 rpm, was higher than that of the previous report, 16rpm.
- ✓ This cross-contamination test was conducted by ASHRAE standard 84-2008 and the pressure difference between SA and RA was strictly controlled to be in 0 or 250 Pa. Contrary this, the pressure difference in the manufacturer's test was not controlled at all, resulting in much amount of the purge air flow.

It was found that the HI-PANEX-Ion enthalpy wheel showed two - fifteen times smaller cross-contamination ratio than that of the 3A molecular sieve wheel for the contaminants tested in this study. Among the tested contaminants, water-soluble ones, ammonia, formaldehyde and Propan-2-ol (Isopropanol) showed somewhat higher values of the cross-contamination than others, but those values were much smaller than those of the 3A molecular sieve wheel. Previous report (Okano et. al., 2001) explained the reason why the ion exchange resin hardly adsorbs odor as follows. Ion exchange resin has no micropore in the dried condition, and gaps filled with water grow when the resin adsorbs humidity, but there is no space capable of adsorbing compounds other than water vapor. Also, the ion exchange resin is a high polymer electrolyte, and its humidity-adsorbing power is produced by its hydration power and osmotic pressure. It adsorbs humidity by a principle similar to the absorbents such as lithium chloride, but it is different from such absorbents in that the ion exchange resin does not change to liquid by dissolving in the adsorbed water even if the resin adsorbs humidity to the saturated condition. Also, in the interior part of the resin, the shrinking power of the cross-linking (swelling pressure) balances osmotic pressure and hydration power working as expanding power, and it may be considered that adsorption and desorption proceed by the difference between inner pressure and outer water vapor pressure. Therefore, the interior of the resin is kept in considerably higher pressure than that of the aqueous solution of the absorbent at the released condition (Applebaum 1968), and the water soluble odor component is hardly dissolved in the water contained in the resin by this inner pressure.

Nevertheless, ammonia showed comparatively high cross-contamination ratio. It was also noticed that the effect of the purge zone, which should be well performed to prevent carry-over by the rotation of the wheel under the larger pressure difference between the supply air and the return air, completely disappeared for ammonia. In contrast, effect of the purge zone could be confirmed in the cases of carbon dioxide and propane-2-ol although the magnitude of the effect seemed to depend on the property of contaminant such as molecular size, polarity and so on. These observation shows that ammonia is the easiest to be adsorbed and transferred by the wheel. This is because ammonia is a water-soluble substance with a molecule diameter that is smaller than that of water vapor, and so ammonia can easily go in and out of micropores. Actually, the molecular sieve effect of synthesized 3A molecular sieve was actually expected, but ammonia has less molecular diameter than water and such an effect could not be obtained.

Table 5 Cross-Contamination ratio of Ammonia

3A molecular sieve wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	1.7	6.0	10.0	5.9	51.8	0.092
	#2	2.0	5.5	10.3	6.3	42.2	0.009
	#3	2.3	6.0	10.3	6.3	46.3	0.031
250Pa	#1	2.0	5.5	9.0	5.3	50.0	0.085
	#2	2.0	5.2	9.9	5.5	40.5	0.051
	#3	2.0	5.4	9.4	5.5	45.9	0.044
	#4	2.1	5.4	9.0	5.0	47.8	0.002
Seibu Giken ion exchange resin wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	0.5	1.8	7.5	6.0	18.6	0.070
	#2	0.9	2.5	9.2	7.0	19.3	0.019
	#3	0.0	2.3	9.9	7.2	23.2	0.082
250Pa	#1	0.0	1.5	7.3	5.2	20.5	0.078
	#2	0.0	1.5	7.1	4.8	21.1	0.040
	#3	0.0	1.5	7.0	4.5	21.4	0.002
	#4	0.8	2.0	7.3	5.2	18.5	0.012

Table 6 Cross-Contamination ratio of Carbon Dioxide

3A molecular sieve wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	503	566	2108	1967	3.9	0.012
	#2	517	554	2134	2002	2.3	0.002
	#3	569	607	2203	2067	2.3	0.001
	#4	584	625	2243	2118	2.5	0.010
250Pa	#1	484	500	2117	1934	1.0	0.010
	#2	506	530	2195	1929	1.4	0.038
Seibu Giken ion exchange resin wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	586	610	2235	2154	1.5	0.043
	#2	587	615	2306	2175	1.6	0.015
	#3	553	579	2245	2145	1.5	0.035
250Pa	#1	530	536	2238	2027	0.4	0.004
	#2	520	533	2205	1989	0.8	0.000
	#3	518	534	2293	2061	0.9	0.001
	#4	514	522	2298	2050	0.4	0.015

Table 7 Cross-Contamination ratio of Formaldehyde

3A molecular sieve wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	0.05	1.04	2.80	1.50	36.0	0.040
	#2	0.05	1.10	3.20	1.76	33.3	0.049
	#3	0.05	1.50	4.00	2.08	36.7	0.048
	#4	0.00	1.25	3.60	1.92	34.7	0.046
Seibu Giken ion exchange resin wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	0.00	0.18	3.04	1.74	5.9	0.280
	#2	0.00	0.13	2.24	1.32	5.8	0.263
	#3	0.00	0.08	1.60	1.08	5.0	0.173
	#4	0.00	0.18	3.20	1.98	5.6	0.228

Table 8 Cross-Contamination ratio of Propan-2-ol

3A molecular sieve wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	0	6	48	36	11.8	0.050
	#2	0	6	45	35	12.6	0.026
	#3	0	6	45	35	12.4	0.004
250Pa	#1	0	4	46	36	9.5	0.100
	#2	0	5	48	36	10.3	0.060
	#3	0	5	47	36	9.7	0.069
	#4	0	5	47	35	9.8	0.063
Seibu Giken ion exchange resin wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	0	2	40	33	5.9	0.008
	#2	0	2	39	34	6.1	0.039
	#3	0	2	39	32	6.4	0.014
250Pa	#1	0	2	40	32	5.5	0.024
	#2	0	2	41	32	5.4	0.005
	#3	0	3	41	33	6.1	0.031
	#4	2	2	42	33	1.2	0.057

Table 9 Cross-Contamination ratio of 4-methyl-2-pentanone (Methyl Isobutyl Ketone; MIBK)

3A molecular sieve wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	0	5	39	30	12.9	0.020
	#2	0	5	40	30	13.3	0.001
	#3	0	5	40	30	13.6	0.024
	#4	0	5	40	30	13.7	0.003
	#5	0	7	52	40	13.0	0.007
	#6	0	7	52	41	13.8	0.025
	#7	0	7	52	40	13.0	0.023

Seibu Giken ion exchange resin wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	3	3	49	43	-0.2	0.008
	#2	1	2	39	34	3.1	0.010
	#3	2	2	41	34	-0.1	0.061
	#4	2	2	40	33	-0.3	0.078
	#5	0	1	42	36	3.2	0.008
	#6	0	1	43	37	3.1	0.016
	#7	0	1	42	35	3.3	0.003

Table 10 Cross-Contamination ratio of p-Xylene

3A molecular sieve wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	1	11	53	36	19.5	0.042
	#2	1	12	53	36	19.7	0.040
	#3	1	11	54	35	19.6	0.063
	#4	2	12	53	36	19.9	0.033

Seibu Giken ion exchange resin wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	0	2	54	45	2.9	0.002
	#2	0	2	53	45	3.0	0.011
	#3	0	2	52	46	3.2	0.057
	#4	0	2	53	45	3.2	0.012

Table 11 Cross-Contamination ratio of Propane

3A molecular sieve wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	3	14	242	223	4.6	0.030
	#2	5	15	250	229	4.1	0.018
Seibu Giken ion exchange resin wheel							
ΔP	RUN	Outside [ppm]	Supply [ppm]	Return [ppm]	Exhaust [ppm]	Cross-Contamination ratio [%]	Error-Mass balance [-]
0Pa	#1	2	4	243	226	0.8	0.010
	#2	2	5	244	225	1.2	0.005

Table 12 Averaged Cross-Contamination ratio of typical contaminants [%]

Contaminant	$\Delta P(\text{SA-RA})=0\text{Pa}$		$\Delta P(\text{SA-RA})=250\text{Pa}$	
	Ion Exchange Resin	3A molecular sieve	Ion Exchange Resin	3A molecular sieve
Ammonia	20.4	46.7	20.4	46.1
Carbon Dioxide	1.5	2.8	0.6	1.2
Formaldehyde	5.6	35.2	-	-
Propan-2-ol (Isopropanol)	6.1	12.3	4.5	9.8
4-methyl-2-pentanone (MIBK)	0.7	13.2	-	-
p-Xylene	3.1	19.7	-	-
Propane	1.0	4.3	-	-

CONCLUSIONS

Cross-contamination of Seibu Giken HI-PANEX-Ion enthalpy wheel was examined and the results were compared with those of a commercialized 3A molecular sieve wheel. It was found that the HI-PANEX-Ion wheel showed smaller cross-contamination ratio than that of the other for all the contaminants tested in this study, ammonia, Carbon Dioxide, formaldehyde, Propan-2-ol (Isopropanol), 4-methyl-2-pentanone (MIBK), p-Xylene and Propane, while the HI-PANEX-Ion wheel indicated almost the same enthalpy exchange efficiency as that of the 3A molecular sieve wheel.

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