CHAPTER IV
RESULTS AND DISCUSSION

This experiment studies hydrogen purification by adsorption. The factors that were studied are type of zeolite, temperature, bead size, initial pressure and the ratio of zeolite and alumina. The life time of the zeolite is also studied.

4.1 Characterization of adsorbents

The commercial adsorbents were used in this experiment are silica gel, activated alumina and 5 different type of zeolite (3A, 4A, 5A, 13X and beta). In order to verify types of zeolite, the XRD spectrum of each sample was compared with the reference patterns collected by International Zeolite Association Structure Commission (IZA-SC). XRD spectrum of zeolite samples were obtained using x-ray diffractometer (Rigaku D/MAX-2200 Ultima$^+$). The XRD spectrum zeolite 3A, 4A, 4A (factory) 5A, beta and 13X exist in the respective sample (Figure 4.1 and 4.2) which correspondent to their structural units.

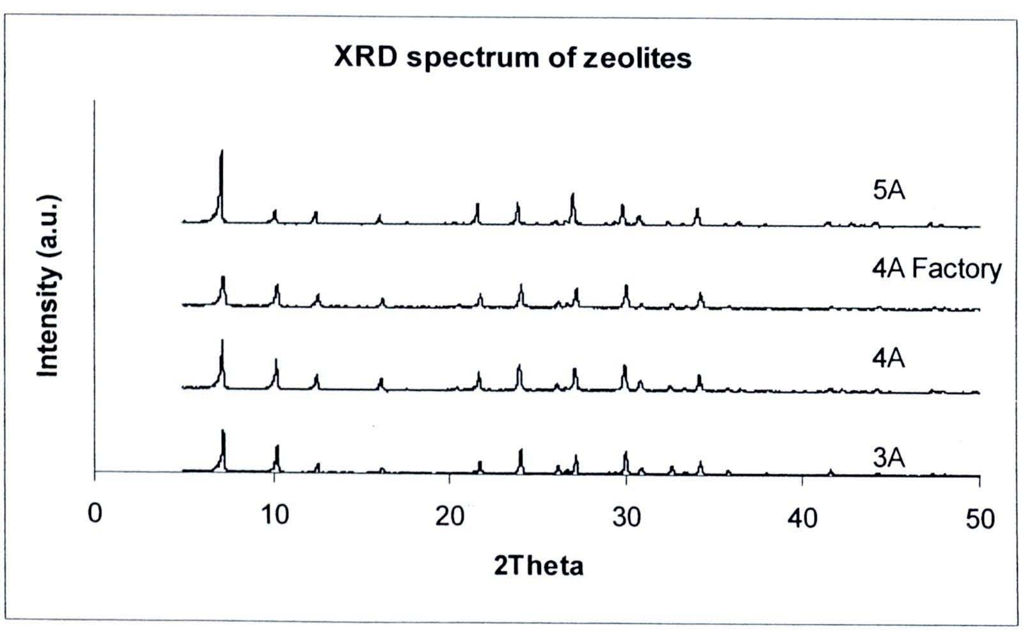

Figure 4.1 XRD spectrum of zeolite 3A, 4A, 4A factory, 5A.

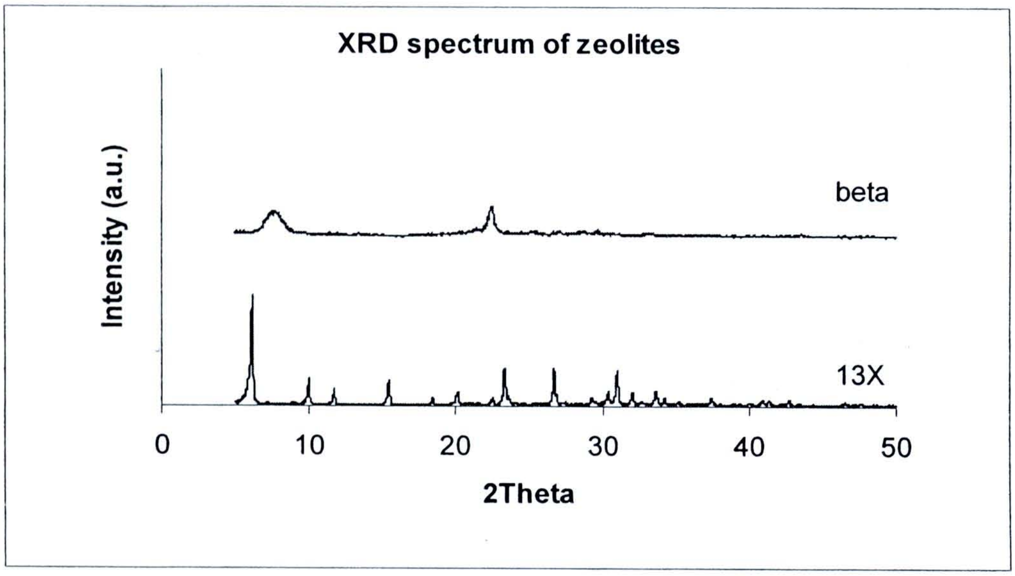

Figure 4.2 XRD spectrum of zeolite beta and 13X.

Surface area of zeolite 13X and beta was analyzed by BEL Japan, BELSORP-mini instrument. The samples were pre-treatment at 300°C for 3 hours. It is unable to analyze surface of zeolite 3A and 4A by this method because the pore size of these zeolites are too small to adsorp N_2. Surface area of zeolite 13X and beta are 531 and 681 (m^2g^{-1}) respectively. N_2 adsorption-desorption isotherms of 13X and beta zeolite are showed in Figure 4.3.

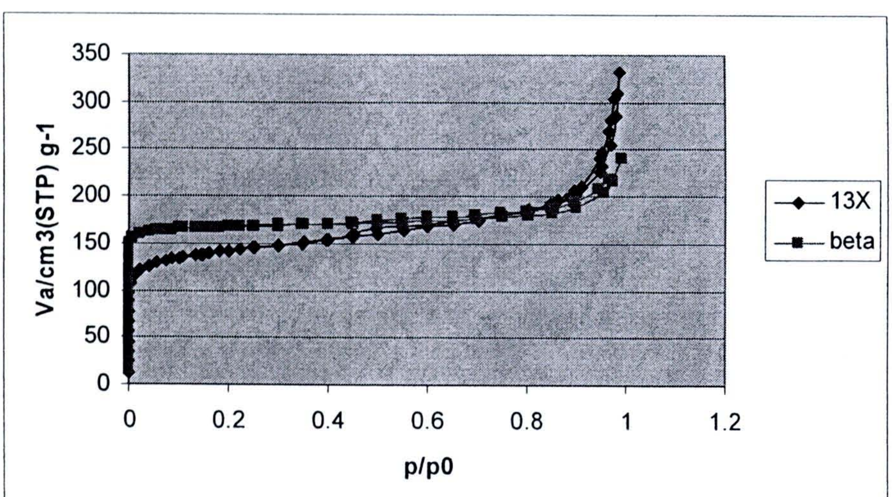

Figure 4.3 N_2 adsorption-desorption isotherms of 13X and beta zeolite.

4.2 Effect of molecular sieve (zeolite)

Effect of molecular sieve (zeolite) was determined by using the standard mixed gas (10.1% CO, 9.9% CO_2, 10.1% CH_4, 10.0% N_2, 59.8% H_2) flows though hydrogen purification system. The condition is shown as below. The obtained results are shown in the table 4.1.

Feed gas	:	standard mixed gas
Zeolite	:	3A, 4A, 5A, 13X and beta
Inlet pressure	:	10 bar g
Temperature	:	-196°C
Pellet size	:	2.5-5 mm.
Alumina : Zeolite : Alumina (g.)	:	4.5 : 3 : 4.5

Table 4.1 Concentration of output gas (zeolite 3A, 4A, 5A, 13X, beta/-196°C/10 barg)

Molecular sieve	Number run	H_2 (%)	N_2 (%)	CO (%)	CH_4 (ppm)	CO_2 (ppm)	Total
3A	1st	91.3	6.0	2.7	434	0	100
	2nd	91.3	5.9	2.8	461	1.1	100
	avg	91.3	6.0	2.8	448	0.6	100
4A	1st	92.1	5.6	2.3	240	0	100
	2nd	91.2	5.9	2.9	460	0	100
	avg	91.7	5.8	2.6	350	0	100
5A	1st	91.0	6.0	2.9	517	1.3	100
	2nd	91.1	6.0	2.9	533	0.3	100
	avg	91.1	6.0	2.9	525	0.8	100
13X	1st	91.0	6.0	3.0	513	1.2	100
	2nd	90.9	6.1	3.0	509	1.0	100
	avg	91.0	6.1	3.0	511	1.1	100
beta	1st	93.5	4.6	1.7	278	0	100
	2nd	93.7	4.6	1.7	277	0	100
	avg	93.6	4.6	1.7	278	0	100

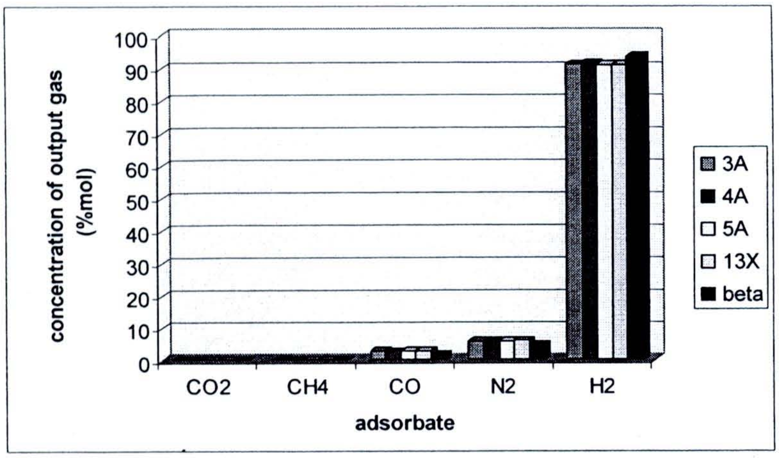

Figure 4.4 Concentration of output gas (zeolite 3A, 4A, 5A, 13X, beta/-196°C/10 barg).

Table 4.2 %Adsorption by zeolite 3A, 4A, 5A, 13X and beta (-196°C/10 barg)

Molecular sieve	% Adsorption			
	N_2	CO	CH_4	CO_2
3A	40.0	72.0	99.6%	99.9%
4A	42.0	74.0	99.7%	100%
5A	40.0	71.0	99.5%	99.9%
13X	39.0	70.0	99.5%	99.9%
beta	54.0	83.0	99.7%	100.0%

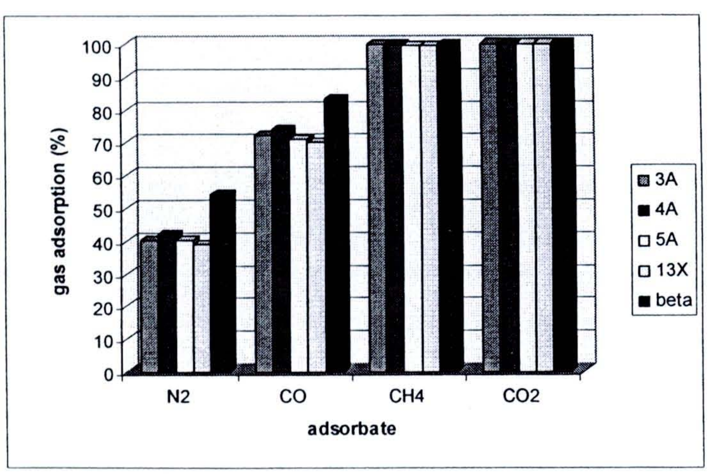

Figure 4.5 %Adsorption by zeolite 3A, 4A, 5A, 13X and beta (-196°C/10 barg).

Purity of hydrogen when using zeolite 3A, 4A, 5A, 13X and beta as adsorbent are 91.3, 91.7, 91.1, 91.0, 93.6% respectively, comparing to 59.8% of inlet standard mixed gas. CO_2 were adsorbed more than CH_4 > CO > N_2 in all type of zeolites. This result corresponds to Peiyuan Li which reported beta zeolite can adsorb CO_2 > CH_4 > N_2 > O_2 [8]. Gas adsorption ability of each zeolite from this experiment is shown below.

N_2 beta > 4A > 3A = 5A > 13X

CO beta > 4A > 3A > 5A > 13X

CH_4 beta > 4A > 3A > 13X > 5A

CO_2 beta > 4A > 3A > 5A > 13X

Beta is a good adsorbent for all of gases. Refer to kinetic diameter theory CO, CO_2, CH_4, N_2 which has a kinetic diameter, σ of 3.76, 3.30, 3.80 and 3.64 Å respectively (Table 4.3). It seems appropriate to zeolite 4A which has a pore diameter of 4 Å. This is compared well to this experiment that adsorption ability of 4A for CO, CO_2, CH_4, N_2 is better than 3A, 5A and 13X. However, from this experiment beta zeolite which has pore diameter of 7.6×6.4 and 5.5×5.5 Å provides the best result for adsorption of CO, CO_2, CH_4, N_2. The result shows that not only pore diameter that affects the adsorption ability. The other factors are zeolite structure and adsorption area. The nitrogen adsorption analysis was done for zeolite beta and 13X. The results are 681 (m^2g^{-1}) and 531 (m^2g^{-1}) respectively which correspond to this experiment. The adsorption ability for N_2 of beta zeolite is better than zeolite 13X.

According to these results, Beta zeolite was chosen to be a representative for the next experiments.

Table 4.3 Dimensions of H_2, N_2, CO, CO_2, CH_4

	Pauling		***Lennard-Jones***	
	length (Å)	**Width (Å)**	**γ min (Å)**	**σ (Å)[a]**
H_2	3.1	2.4	3.24	2.89
N_2	4.1	3	4.09	3.64
CO	4.2	3.7	4.25	3.76
CO_2	5.1	3.7		3.30
CH_4		4.2	4.25	3.80

[a] Kinetic diameter, σ calculated from the minimum equilibrium cross-sectional diameter.

4.3 Effect of the temperature

Effect of temperature was determined by using the following conditions. The results are shown in the table 4.4.

Feed gas	:	standard mixed gas
Zeolite	:	Beta
Initial pressure	:	10 barg
Temperature	:	-196°C, 0°C, ambient (25°C)
Pellet size	:	2.5-5 mm.
Alumina : Zeolite : Alumina (g.)	:	4.5 : 3 : 4.5

Table 4.4 Concentration of output gas (beta zeolite/-196°C, 0°C, ambient/10 barg)

Molecular sieve	Number run	H_2 (%)	N_2 (%)	CO (%)	CH_4 (%)	CO_2 (%)	Total
Beta	1st	93.5	4.6	1.7	277 ppm	0	100
-196°C	2nd	93.7	4.6	1.7	277 ppm	0	100
	avg	93.6	4.6	1.7	277 ppm	0	100
Beta	1st	62.6	10.4	10.3	10.4	6.6	100
0°C	2nd	62.0	10.3	10.1	10.1	7.3	100
	avg	62.3	10.4	10.2	10.3	7.0	100
Beta	1st	61.4	10.2	10.1	10.3	7.9	100
ambient	2nd	61.7	10.2	10.2	10.3	7.6	100
	avg	61.6	10.2	10.2	10.3	7.8	100

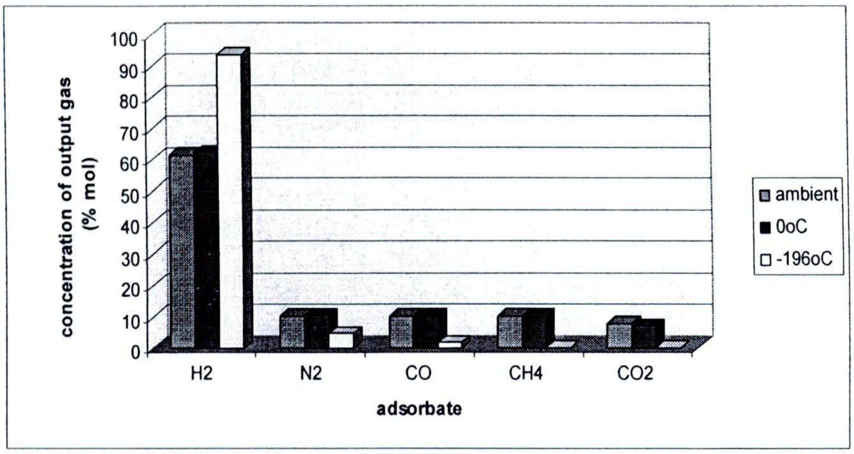

Figure 4.6 Concentration of output gas (beta zeolite/-196°C, 0°C, ambient/10 barg).

The purity of hydrogen when using beta zeolite at -196°C, 0°C, ambient are 93.6%, 62.3%, 61.6% respectively. The result at -196°C is obviously better than at 0°C and ambient. Beta zeolite does not adsorb N_2, CO, CH_4 at 0°C and ambient, only CO_2 will be adsorbed. The purity of hydrogen at 0°C are better than at ambient (25°C). This can be concluded that decreasing the temperature of the gas-solid system at a constant pressure will increase the quantity of *x* adsorbed.

$$X = f(t)_p$$

This is because gas molecules, upon collision with cooled surfaces, lose a significant amount of their thermal energy to the cooled surface. In general it may be said that the thermal energy of a gas molecule is determined almost entirely by the temperature of the last surface where the gas molecule desorbed from. If a surface is intentionally cooled to the temperature of liquid nitrogen (-196°C or 77K), all gas molecules which have a boiling point higher than -196°C can be cryo-condensed on this surface. These gas molecules will literally freeze, transforming from a gas to a solid. As solid material, these condensed gases are capture [15]. Table 4.5 shows boiling and melting point of CO, CO_2, CH_4, N_2 and H_2 respectively. At -196°C, solid property of CO_2 is more than CH_4 and liquid property of CO is more than N_2 which correspond to the results that CO_2 can be adsorped more than CH_4 > CO > N_2. According to the result decreasing the temperature will increase gas adsorption. This corresponds to Vithitsan's experiment which reported that adsorption of moisture on zeolite 3A at 90°C is better than 110°C [11] and Peiyuan Li which reported that with beta zeolite, the kinetic separation factors are very small at high temperatures for all system studied (CH_4/N_2, CH_4/O_2, N_2/O_2, N_2/CO_2, O_2/CO_2) [8].

Table 4.5 boiling and melting point of CO, CO_2, CH_4, N_2 and H_2

Gas type	Boiling point (°C)	Melting point (°C)	State at -196°C
CO	-192	-205	liquid
CO_2	-78	-57	solid
CH_4	-161.6	-185.5	solid
N_2	-195.79	-210	liquid
H_2	-252.87	-259.14	gas

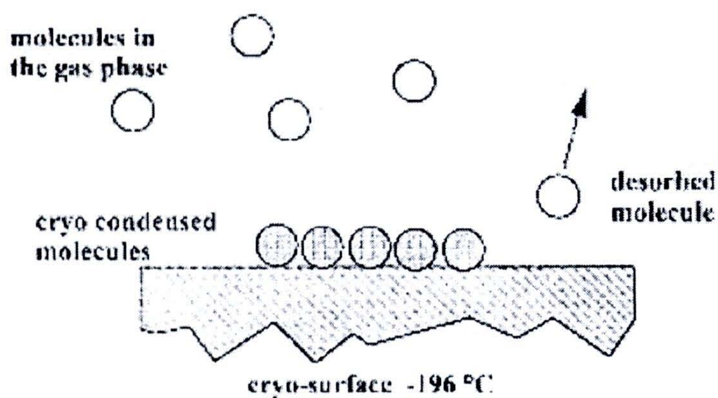

Figure 4.7 Molecules in the gas phase, upon contact with a liquid nitrogen temperature surface, condense on that surface. The residence time for molecules is dependent upon the species of gas, the temperature of the cryo-surface and the heat of adsorption.

From the temperature study, the temperature of -196°C was chosen for the next experiments.

4.4 Effect of the inlet pressure

Effect of the initial pressure was determined by using the following conditions. The results are shown in the table 4.6.

Feed gas	:	standard mixed gas
Zeolite	:	Beta
Inlet pressure	:	5, 10, 15, 20 barg
Temperature	:	-196°C
Pellet size	:	2.5-5 mm.
Alumina : Zeolite : Alumina (g.)	:	4.5 : 3 : 4.5

Table 4.6 Concentration of output gas (beta zeolite/-196°C/5, 10, 15, 20 barg)

Molecular sieve	Number run	H_2 (%)	N_2 (%)	CO (%)	CH_4 (ppm)	CO_2 (ppm)	Total
5 barg	1st	94.3	4.3	1.4	258	0.4	100
	2nd	93.2	4.7	1.7	282	0.6	100
	avg	93.8	4.5	1.6	270	0.5	100
10 barg	1st	93.5	4.6	1.7	278	0	100
	2nd	93.7	4.6	1.7	277	0	100
	avg	93.6	4.6	1.7	278	0	100
15barg	1st	91.3	6.0	2.7	439	1.3	100
	2nd	90.9	6.2	2.8	528	1.0	100
	avg	91.1	6.1	2.8	484	1.2	100
20barg	1st	89.8	6.9	3.3	627	1.0	100
	2nd	91.3	6.0	2.7	467	1.6	100
	avg	90.6	6.5	3.0	547	1.3	100

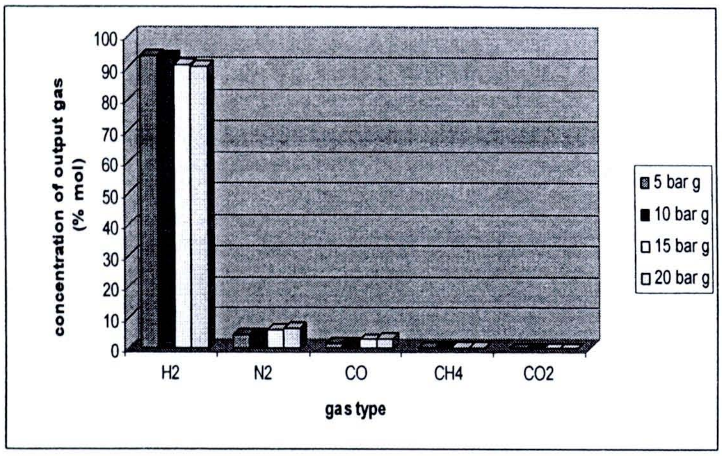

Figure 4.8 Concentration of output gas (beta zeolite/-196°C/ 5, 10, 15, 20 barg).

Purity of hydrogen will be increased when decreasing the inlet pressure. The purity of hydrogen at 5, 10, 15, 20 barg are 93.8, 93.6, 90.9, 90.6% respectively. This is explained by the adsorption time. At low pressure, the flow rate is also low. Therefore, there is much time for adsorption. This corresponds to Vithitsan's experiment which reported that adsorption of moisture on zeolite 3A at 1 mL/min. is better than 2 mL/min [11].

The adsorption pressure can be fixed by either available feed pressure or the required product pressure. Although a high feed gas pressure is always preferred for high hydrogen recovery and low investment costs but the purity of hydrogen is decreased.

In this experiment, the purity of hydrogen at 5 and 10 barg are not much different. To increase the productivity, pressure 10 barg was chosen for the next experiments.

4.5 Effect of the pellet size

In order to utilize the adsorption characteristics of zeolites in separation processes, commercial molecular sieve adsorbents are prepared as pelleted agglomerates containing a high percentage of the crystalline zeolite together with the necessary amount of an inert binder. The effect of pellet size was studied by using the 2.5-5 mm. and 1-2 mm. of zeolite 3A. The condition is below. The results are shown in the table 4.7.

Feed gas	:	standard mixed gas
Zeolite	:	3A

Initial pressure : 10 barg

Temperature : -196°C

Pellet size : 2.5-5 mm., 1-2 mm.

Alumina : Zeolite : Alumina (g.) : 4.5 : 3 : 4.5

Table 4.7 Concentration of output gas (2.5 mm.,1-2 mm. of zeolite 3A/-196°C/10 barg)

Molecular Sieve	# run	H_2 (%)	N_2 (%)	CO (%)	CH_4 (ppm)	CO_2 (ppm)	Total
Beta	1st	93.5	4.6	1.7	278	0	100
(2.5-5	2nd	93.7	4.6	1.7	277	0	100
mm.)	avg	93.6	4.6	1.7	278	0	100
3A	1st	91.3	6.0	2.7	434	0	100
(2.5-5	2nd	91.3	5.9	2.8	461	1.1	100
mm)	avg	91.3	6.0	2.8	448	0.6	100
3A	1st	91.0	6.0	2.9	511	0.4	100
(1-2 mm)	2nd	90.9	7.2	1.8	557	1.8	100
	avg	91.0	6.6	2.4	534	1.1	100

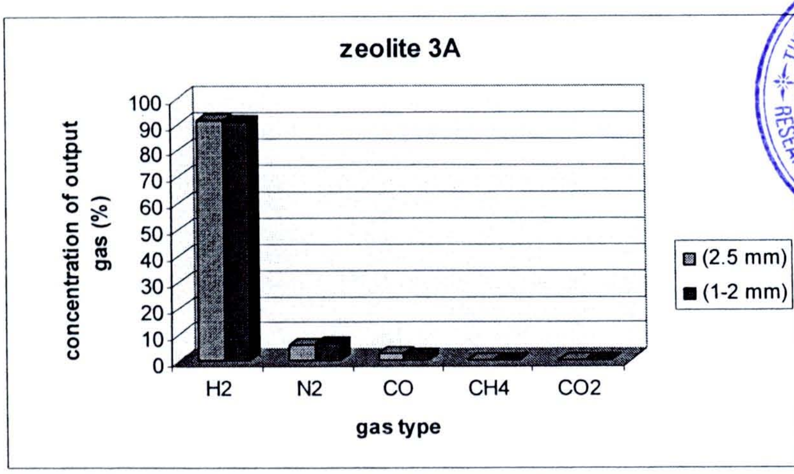

Figure 4.9 Concentration of output gas (2.5 mm.,1-2 mm. of ziolite 3A/-196°C/10 barg).

Purity of hydrogen when use 2.5-5 mm. and 1-2 mm. of zeolite 3A, -196°C are 91.3% and 91.0% respectively. The results are not much different. This is because adsorption is a matter of pore filling. The external surface area which takes a few percent of the total area doesn't play an important role in adsorption for this case.

4.6 Effect of ratio between alumina and zeolite

In this experiment alumina and zeolites were used to adsorb gas impurities of hydrogen. Effect of ratio between alumina and zeolite was studies. The condition is following. The results are shown in the table 4.8.

Feed gas	:	standard mixed gas
Zeolite type	:	3A, beta
Inlet pressure	:	10 barg
Temperature	:	-196°C
Pellet size	:	2.5 mm.
Adsorbent ratio		
Alumina:Zeolite:Alumina (g.)	:	0 : 12 : 0
	:	6 : 0 : 6
	:	4.5 : 3 : 4.5
	:	2.5 : 7 : 2.5

Table 4.8 Concentration of output gas by vary ratio of alumina and zeolite.

Molecular sieve	**Ratio(alumina: zeolite:alumina) (g)**	**# run**	**H_2 (%)**	**N_2 (%)**	**CO (%)**	**CH_4 (ppm)**	**CO_2 (ppm)**	**Total**
		1st	93.7	4.4	1.8	422	0	100
Beta	(0:12:0)	2nd	94.5	3.8	1.6	441	0	100
		avg	94.1	4.1	1.7	432	0	100
		1st	87.7	7.2	4.7	1361	0	100
3A	(0:12:0)	2nd	87.8	7.3	4.7	1377	0	100
		avg	87.8	7.3	4.7	1369	0	100
		1st	92.0	5.7	2.4	370	0.1	100
Alumina	(6:0:6)	2nd	92.1	5.4	2.4	322	0.1	100
		avg	92.1	5.6	2.4	346	0.1	100

Molecular sieve	Ratio (alumina: zeolite: alumina) (g.)	# run	H_2 (%)	N_2 (%)	CO (%)	CH_4 (ppm)	CO_2 (ppm)	Total
beta	(4.5:3:4.5)	1st	93.5	4.6	1.7	278	0	100
		2nd	93.7	4.6	1.7	277	0	100
		avg	93.6	4.6	1.7	278	0	100
	(2.5:7:2.5)	1st	93.5	4.7	1.7	380	0	100
		2nd	93.5	4.8	1.7	292	0	100
		avg	93.5	4.8	1.7	336	0	100
3A	(4:5:3:4.5)	1st	91.3	6.0	2.7	434	0	100
		2nd	91.3	5.9	2.8	461	1.1	100
		avg	91.3	6.0	2.8	448	0.6	100
	(2.5:7:2.5)	1st	89.9	6.5	3.6	691	0	100
		2nd	89.8	6.4	3.7	746	1	100
		avg	89.9	6.5	3.7	719	0.5	100

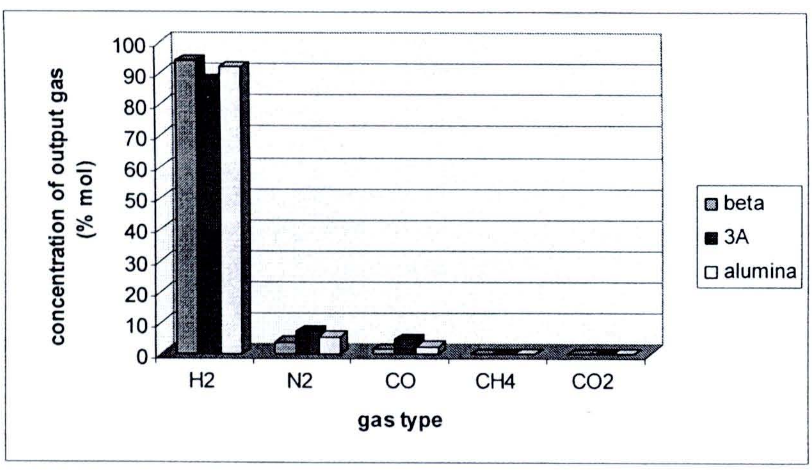

Figure 4.10 Concentration of output gas (zeolite 3A, beta, alumina (12g.)/-196°C/10 barg.).

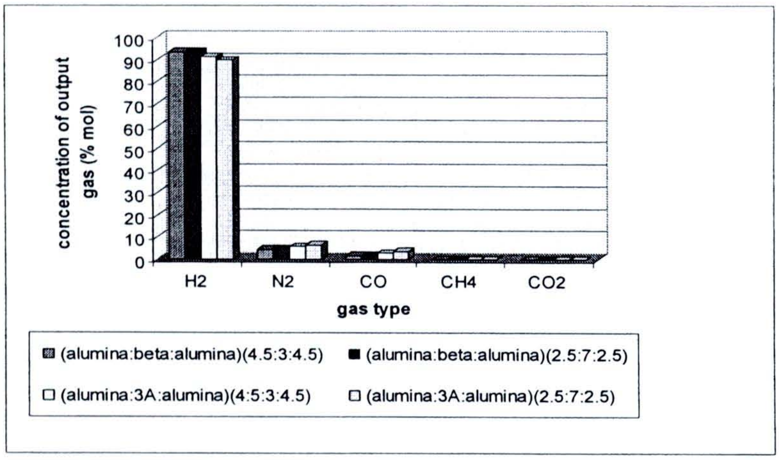

Figure 4.11 Concentration of output gas (zeolite 3A, beta/alumina:zeolite; 9:3, 5:7/-196°C/10 barg).

Purity of hydrogen when use 100% of zeolite beta, 3A and alumina are 94.1, 87.8, 92.1 respectively. The adsorption ability of zeolites and alumina are shown below.

N_2	beta > alumina > 3A
CO	beta > alumina > 3A
CH_4	alumina > beta > 3A
CO_2	beta = 3A > alumina

Alumina can adsorb CH_4 well, when beta can adsorb N_2, CO and CO_2 well. Increasing the alumina content would make CH_4 adsorption much better. This result corresponds to mixing alumina and zeolite adsorbent. At higher alumina content adsorbent, it exhibits lower CH_4 content of outlet gas in both cases of beta and 3A zeolites. However the most appropriate ratio is 4.5 : 3 : 4.5 of alumina : zeolite : alumina which makes the hydrogen purity to be 93.6% in case of beta zeolite is an adsorbent.

Activated alumina does not possess an ordered crystal structure and consequently the pores are nonuniform. The distribution of the pore diameters within the adsorbent particles may be narrow (20 to 50 Å) or it may range widely (20 to several thousand Å). Hence, all molecular species, with the possible exception of high molecular weight polymeric materials, may enter the pores. The major use of activated alumina as a sorbent is in drying. The moisture content can be reduced to below 1 ppm using activated alumina in suitable designed adsorbers.

Zeolite molecular sieves have pores of uniform size (3Å to 10Å) which are uniquely determined by the unit structure of the crystal. These pores will completely exclude molecules which are larger than their diameter [6].

4.7 Life time of adsorbents

All adsorption systems are cyclic in nature i.e. there is an adsorption cycle followed by regeneration cycle, which enables repeated use of adsorbent. In this experiment, the thermal was employed for regeneration and the stability period of the zeolite was studied. Four times of calcination (300°C for zeolite beta and 180°C for alumina, 3 hours) are done and hydrogen purification are repeated by using the following condition. The results are in the table 4.9 and figure 4.12.

Feed gas	:	standard mixed gas
Zeolite	:	beta
Initial pressure	:	10 barg
Temperature	:	-196°C
Pellet size	:	2.5-5 mm.
Alumina : Zeolite : Alumina (wt)	:	4.5 : 3 : 4.5

Table 4.9 Concentration of output gas after each calcination (beta zeolite/-196°C/10 barg).

	# run	H_2 (%)	N_2 (%)	CO (%)	CH_4 (ppm)	CO_2 (ppm)	Total
Calcination 1st	1st	93.5	4.6	1.7	278	0	100
	2nd	93.7	4.6	1.7	277	0	100
	avg	93.6	4.6	1.7	278	0	100
Calcination 2nd	1st	91.9	5.5	2.5	319	0.1	100
	2nd	91.6	5.6	2.8	422	0	100
	3rd	92.8	5.0	2.2	322	0	100
	avg	92.1	5.4	2.5	354	0.05	100
Calcination 3rd	1st	92.8	5.0	2.1	262	0	100
	2nd	91.9	5.4	2.6	326	0.07	100
	avg	92.4	5.2	2.4	294	0.04	100
Calcination 4th	1st	92.7	5.2	2.1	264	0	100
	2nd	92.3	5.4	2.3	332	0	100
	avg	92.5	5.3	2.2	298	0.00	100

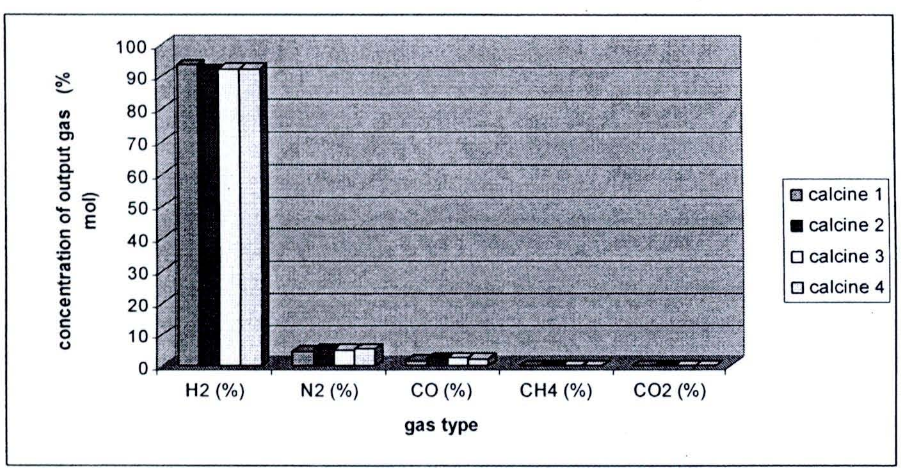

Figure 4.12 Concentration of output gas after each calcination (beta zeolite/-196°C/ 10barg).

Hydrogen concentration of output gas after 1st, 2nd, 3rd, 4th calcinations is 93.6, 92.1, 92.4, 92.5 respectively. The concentration of hydrogen after the second time of regeneration is less that the first one around 1.6%. The concentration of hydrogen after the 2nd, 3rd, 4th of regeneration is not much different. This result corresponds to the Shang-Bin Liu's experiment which reported that the structure of beta zeolite is a small destruction at 400°C [12].

4.8 Comparison the best and present condition.

The present and the best condition are compared by using standard mix gas and hydrogen (industrial grade) as an inlet gas. The condition is below. The results are in the table 4.10.

		Best condition	**Factory condition**
Feed gas	:	standard mixed gas	
	:	H_2 industrial grade	
Zeolite	:	beta	4A (Factory)
Inlet pressure	:	10 barg	15 barg
Temperature	:	-196°C	-196°C
Pellet size	:	2.5-5 mm.	2.5-5 mm.
Alumina:Zeolite:Alumina (g.)	:	4.5:3:4.5	4.5 : 3 : 4.5

Table 4.10 Compare concentration of output gas by present factory condition and best condition.

Feed Gas	Condition	# run	H_2 (%)	N_2 (%)	CO (%)	CH_4 (ppm)	CO_2 (ppm)	Total
Standard Mixed Gas	Factory Condition	1st	90.3	6.6	3.1	482	0.9	100
		2nd	90.3	6.4	3.3	641	0.6	100
		avg	90.3	6.5	3.2	562	0.8	100
	Best Condition	1st	93.5	4.6	1.7	278	0	100
		2nd	93.7	4.6	1.7	277	0	100
		avg	93.6	4.6	1.7	278	0	100

Feed Gas	Condition	# run	O_2 (ppm)	N_2 (ppm)	CO (ppm)	CH_4 (ppm)	CO_2 (ppm)	Total Impurity (ppm)	Total H_2 purity (%)
H_2 Ind.			5.8259	1.7145	2.3011	0	1.2459	9.8415	99.9990
H_2 Industrial Grade (99.8%)	Factory Condition	1st	2.0341	0.5369	1.5297	0	0	4.1007	99.9996
		2nd	2.0886	0.6152	1.7105	0	0	4.4143	99.9996
		avg	2.0614	0.5761	1.6201	0	0	4.2576	99.9996
	Best Condition	1st	0.7716	0.3019	0.2913	0	0	1.3648	99.9999
		2nd	1.3346	0.1957	0.2894	0	0	1.8197	99.9998
		avg	1.0531	0.2488	0.2903	0	0	1.5922	99.9999

Table 4.11 Product specification of hydrogen

Gas	**Typical Level**	**Production Specification**	**Selling Specification**
Hydrogen, industrial grade (99.8%)	Purity 99.8%min O_2 < 200 ppm H_2O < 200 ppm N_2 < 1000 ppm	Purity 99.8%min O_2 < 200 ppm H_2O < 200 ppm	Purity 99.8% min
Hydrogen, UHP (99.999%)	Purity 99.999%min. O_2 < 2 ppm H_2O < 3 ppm THC as CH4 < 1 ppm N_2 < 4ppm CO < 0.5ppm CO_2 < 1ppm	Purity 99.999%min O_2 < 2 ppm H_2O < 3 ppm THC as CH_4 < 1 ppm	Purity 99.999%min O_2 < 2 ppm H_2O < 3 ppm THC as CH_4 < 1 ppm

source : Thai Industrial Gases (Public) Co.,Ltd.

The hydrogen concentration of output gas after using standard mixed gas as a feed gas with the present factory condition and our best condition are 90.3% and 93.3% respectively. When hydrogen industrial grade was used as a feed gas with the present and our best condition, the hydrogen concentration are 99.9996 and 99.9999% respectively. The purity of hydrogen after using our best condition is better than the specification. Especially, O_2 and CO levels are lower than maximum limit of UHP H_2 gas specification. This beta zeolite adsorbent exhibits the superior property than the present factory condition. Therefore, it can be concluded that the suitable zeolite for hydrogen purification by absorption process is beta zeolite. The inlet pressure is 10 barg and the temperature is -196°C. The pellet size is 2.5-5 mm. and the ratio of alumina:zeolite:alumina is 4.5:3:4.5. By this condition hydrogen purity would increase up to 99.9999%. This would raise the product quality and make it is valuable.