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Investigation of Natural Gas Dehumidification through Adsorption in One of the CNG Stations in Mazandaran Province

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ABSTRACT

Natural gas dehumidification is a critical stage in the refining process to ensure the quality of Compressed Natural Gas (CNG). This study investigates the performance of an industrial dehumidification unit at a CNG station in Jouybar, Mazandaran, utilizing a dual-bed system packed with Molecular Sieve A3 and Activated Alumina. The primary objective was to evaluate the impact of varying adsorption cycle times (ranging from 6 to 36 hours) on the water removal efficiency, while maintaining a fixed regeneration interval. The performance was assessed by measuring the quantity of desorbed water and condensed heavy hydrocarbons (organic impurities) during the regeneration phase. The results indicated that the adsorption efficiency is significantly dependent on the cycle duration. The maximum specific water desorption was observed in the 6-hour cycle, achieving approximately 3.50 g of water per kg of adsorbent. In contrast, extending the cycle to 36 hours drastically reduced water removal to 0.49 g/kg. Analysis revealed that during longer cycles, the co-adsorption of heavy hydrocarbons (e.g., pentane and hexane) blocks the adsorbent pores, creating mass transfer resistance and preventing effective water uptake. Furthermore, the fixed regeneration time was insufficient for fully cleaning the saturated beds in longer cycles. Consequently, to maintain the outlet gas moisture content below the permissible limit (mass fraction of 36.70 ppm), reducing the adsorption cycle time to 6 hours is recommended to mitigate organic fouling and ensure complete adsorbent regeneration.

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1. Introduction

Dehumidification of gas through adsorption is a critical industrial process governed by both kinetic mechanisms and thermodynamic equilibrium. While kinetic models describe the time-dependent pathways and rate-controlling steps such as surface adsorption and intraparticle diffusion (Caqueret et al., 2008) equilibrium isotherms (e.g., Langmuir, Freundlich, Temkin, and BET) are fundamental for determining maximum adsorbent capacity and optimizing design parameters (Snurr et al., 1993; Nemr, 2009). However, in most literature, these mathematical models are applied under highly simplified, static, or pure-gas conditions. In industrial-scale operations, the dynamic interplay of multi-component feed gas, pressure fluctuations, and competing contaminants severely limits the direct applicability of idealized kinetic and equilibrium assumptions. Therefore, while these models establish a theoretical baseline, empirical validation and operational evaluation under actual field conditions remain essential to bridge the gap between theory and practice.

A fixed-bed TSA system for natural-gas dehydration using activated alumina and molecular sieve adsorbents has been modeled, showing that simulation tools can successfully predict outlet moisture reduction under controlled operating conditions (Mehrpooya and Ghasemzadeh, 2020; Palomba et al., 2021). A two-layer adsorption bed was investigated, and improved breakthrough time and reduced energy consumption were reported compared with a single-layer configuration (Tavan et al., 2019). Water adsorption on zeolite 13X in a fixed-bed reactor was examined, revealing rapid adsorption kinetics and a high moisture-uptake capacity (Mette et al., 2014). Experimental results showed that increasing the gas flow rate and inlet water content can reduce water-removal efficiency in natural-gas dehydration systems (Farag et al., 2011). A commercial-scale dehydration unit was simulated, demonstrating that fixed-bed adsorption could reduce the outlet water content below the standard limit while also providing information on the development of the mass-transfer zone during the adsorption cycle (Aleghafouri and Davoudi, 2018). Activated alumina has also been investigated as an effective adsorbent for moisture removal due to its high surface area and water-sorption capacity (Takbiri et al., 2013). TSA in a multilayer adsorbent bed was studied, showing that multilayer configurations can improve vapor-breakthrough performance compared with single-layer systems (Nastaj and Ambrożek, 2015). A mathematical model for moisture adsorption in fixed beds was developed and validated, demonstrating the effects of particle size, tortuosity, and pressure drop on breakthrough behavior (Gholami et al., 2010). Other studies have examined alternative dehydration approaches such as low-temperature packed columns and thermodynamic optimization of glycol-based systems (Rubaiee, 2023).

Despite the extensive literature on natural gas dehydration, several important gaps remain. Most previous studies have mainly focused on laboratory-scale adsorption systems, numerical simulations, or idealized operating conditions, whereas limited experimental evidence is available from full-scale industrial CNG stations operating under real field conditions. In industrial hydrocarbon-processing units, the accumulation of heavy hydrocarbons and deposit formation under prolonged residence time and temperature gradients has been reported as a major operational concern, significantly affecting mass-transfer performance and process efficiency (Hasanpour et al., 2025). However, the potential impact of such organic fouling phenomena on industrial adsorption beds for natural-gas dehydration has not been sufficiently clarified. Moreover,

the combined effects of adsorption-cycle duration, co-adsorption of heavy hydrocarbons, and fixed regeneration time on the long-term performance of industrial adsorption beds remain inadequately understood. Therefore, the novelty of the present study lies in the field-scale experimental evaluation of an operating industrial dehydration unit at a CNG station in Mazandaran Province, with particular emphasis on optimizing adsorption-cycle time and identifying the role of organic fouling in reducing water-adsorption efficiency under practical operating constraints.

In this study, the moisture content and temperature of the gas at the inlet and outlet of the bed were examined at different time intervals. The moisture content of the gas exiting the column during the regeneration phase was examined over a period of 240 minutes. The regeneration process is characterized by two distinct periods: the warming of the adsorbent, which corresponds to the first 90 minutes, where the output moisture is between 0.5 and 0.9 g/Cm3. After that, up to 120 minutes, the amount of water removed reaches a maximum of 3.75 g/Cm3. From 120 to 200 minutes, the average moisture concentration drops to 0.5 g/Cm3, and finally, at 240 minutes, it decreases to less than 0.005 g/Cm3. In the analysis of adsorption equilibrium, the Langmuir isotherm equation was used to determine the amount of moisture adsorbed at different input concentrations and temperatures. By examining the changes in moisture content in the output gas over time, it was found that the moisture level in the output during the 4-hour adsorption-regeneration cycle did not exceed the permissible limit. By examining the temperature changes near the inlet and outlet of the tower during the regeneration phase, it was observed that the temperature at the tower inlet initially increases rapidly and then stabilizes. The temperature variations at the outlet are minimal.

2. Methods

The system under investigation consists of the natural gas feed entering the CNG station, which is composed of polar gases. (Table 1) provides the specifications for the molecular sieve A3, while (Table 2) presents the specifications for activated alumina (XINTAO, n.d.).

Table 1: Physical and Chemical Properties of Molecular Sieve A3

Specifications	Type / Amount	Unit
Color	Light gray	-
Nominal diameter of holes	3	Å
Shape	Spherical	-
Diameter	3-5	mm
Size distribution	≥98	%
Bulk density	≥0.70	g/ml
Water ratio	≤0.20	wt%
Static water absorption	≥21.00	wt%
Dynamic capacity	≥20.00	%
Ethylene absorption	≤3.00	wt%
Water content	≤1.50	wt%
General chemical formula	$4K_2O.\ 6NaO_2.\ Al_2O_3.\ 2SiO_2.\ 4.5H_2O(SiO_2{:}Al_2\ O_3{\sim}2)$	_

Table 2: Specifications of Active Alumina Adsorbent

Specifications	Amount	Unit
Appearance/Color	Spherical/White	-
$Al_2O_3 \geq 93$	%	Compositions
$SiO_2 \leq 0.05$		
$Fe_2O_3 \leq 0.05$		
$NO_2O_3 \leq 0.35$		
Loss on ignition (250-1100°C ≤ 7)		
Adsorbent diameter range	4-8	millimeter
Bulk density	700	g/lit
Total pore volume	40	$cm^3/100g$
Specific surface area	≥330	m^2/g
Abrasion	Maximum 0.2	wt%
Mechanical resistance	150	Newton/particle
Moisture content	Maximum 1	wt%
Adsorption capacity at %60 relative humidity and 20°C	21	wt%
Adsorption capacity at %10 relative humidity and 20°C	Minimum 7	wt%

The system under review is a natural gas dehydration unit at the CNG station located in Jouybar, Mazandaran Province. The station has a compressor output flow rate of 1200 m3/hr and an input pressure of 250 psi. The unit in question includes equipment such as adsorption-desorption towers, blowers, filters, electric heaters, separators, collectors, and coolers. The system consists of two adsorption columns arranged in parallel in the process configuration; however, they operate alternately in a cyclic mode. While one bed is in the adsorption step, the other undergoes regeneration, and the two beds switch roles after each operating cycle. The control system, upon receiving a signal indicating that the compressor is active, first initiates a 24-hour cycle for one of the adsorption towers. After the completion of the 24-hour cycle of the first tower, if the manual mode is selected (meaning the dew point sensor is turned off), the second tower begins its 24-hour adsorption cycle. During the adsorption process, the wet natural gas, at a pressure of 250 psi and at ambient temperature, passes through the inlet filter to trap oily substances and impurities, then enters the adsorption tower from the top and flows downwards into the bed. (Figure 1) shows the P&ID of the moisture adsorption-desorption process from natural gas at the CNG station.

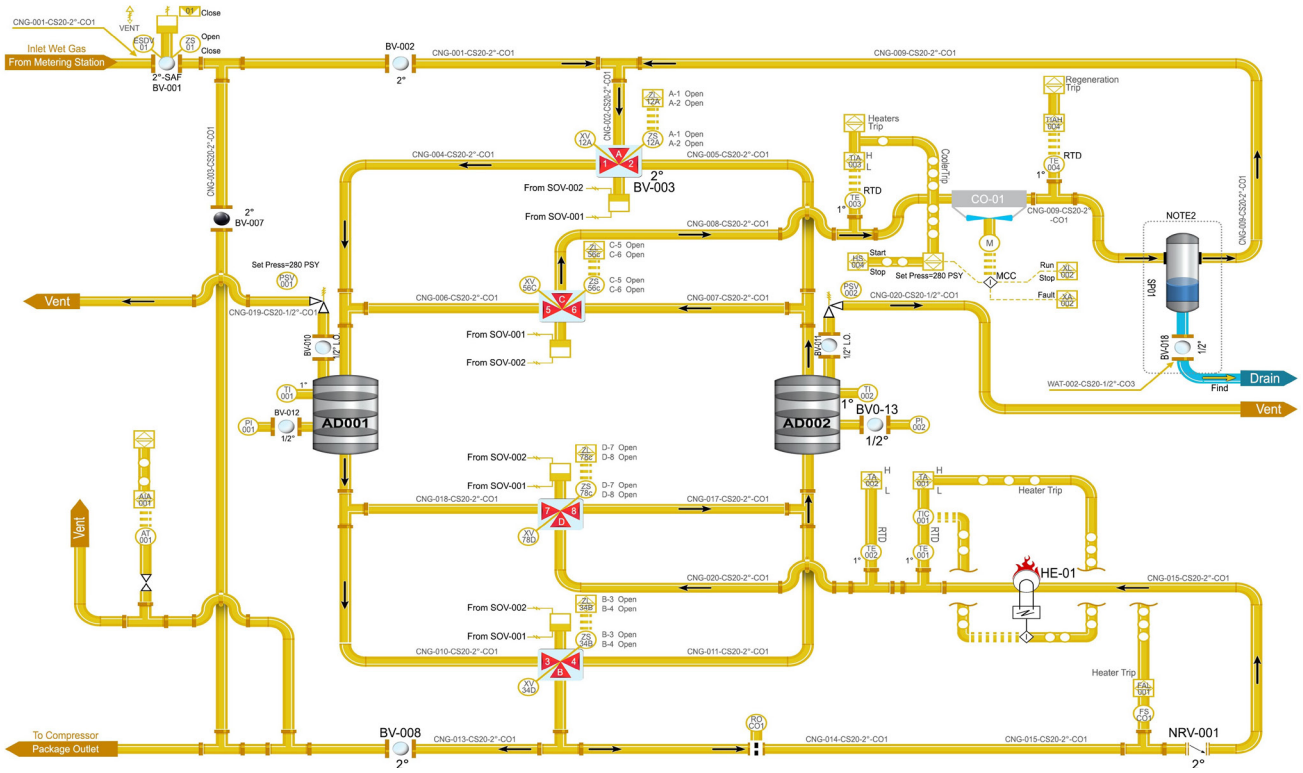


Figure 1. P&ID of the Moisture Adsorption-desorption Process from Natural Gas at the CNG Station

3. Method of Examination

In this study, the dehydration performance of the CNG station was investigated by varying the adsorption cycle time. The fixed operating parameters were the inlet gas temperature, gas pressure, gas flow rate, gas velocity, inlet water mass fraction, and regeneration gas temperature. The main variable parameter was the adsorption cycle time, and the measured response was the cumulative amount of moisture desorbed in each cycle, which was taken to represent the amount of moisture previously adsorbed.

In principle, the performance of the dehydration unit can be influenced by both regeneration gas temperature and regeneration cycle time. In the present system, the regeneration gas temperature ranges from 180 to 220°C; however, this parameter was not varied in this study due to the operational hazards associated with increasing temperature. In addition, complete regeneration was assumed, i.e., the amount of moisture desorbed was considered equal to the amount of moisture adsorbed. Therefore, under the operating conditions of this study, the adsorption cycle time was selected as the only independent variable, while the remaining parameters were kept constant. For the purpose of estimating the moisture uptake from the measured desorbed water, the analysis initially assumes complete regeneration in each cycle; therefore, the amount of desorbed moisture is taken as an approximation of the amount adsorbed in the preceding adsorption step. However, this assumption is used as a simplifying basis for calculation and may not fully hold under longer adsorption cycles, where regeneration can become less complete. To ensure that the observed performance variations were mainly due to the duration of the absorption cycle, key operating parameters were closely monitored. The feed gas composition remained relatively stable throughout the study period and was consistent with the standard pipeline gas quality. The pressure and flow rate were

controlled by the station's automatic regulation system and the deviations were kept within ±2% of the nominal values. In addition, the operating temperature was recorded using calibrated industrial sensors to ensure that any fluctuations remained within the typical range for seasonal operating conditions in the Mazandaran region.

4. Experimental Method

Since our variable parameter in this system is the adsorption time, the change in the adsorption cycle time is manually set through the Human-Machine Interface (HMI) screen located in the control room to times of (36, 30, 27, 24, 21, 18, 15, 12, 10, 8, 6) hours. At the start of each operating cycle, one bed enters the adsorption stage while the second bed enters the regeneration stage; thus, the two beds operate in complementary alternating modes. While moisture absorption by the adsorbents is taking place in the adsorption tower, after 70 minutes, the desorption phase of the regeneration tower is completed, and the regeneration tower is prepared to start the next adsorption cycle. The gas exiting the regeneration tower, after passing through the cooler and being cooled, goes to the separator, where the moisture resulting from condensation is transferred to the collector. Adsorption continues until the set time (adsorption cycle) displayed on the HMI is reached, and as soon as the set temperature is achieved, the tower switch occurs. This adsorption and desorption cycle is continuously repeated after specified time cycles. Meanwhile, the liquid collected in the collector, which results from the condensation of gas exiting the regeneration tower, is discharged and taken to the laboratory for separation and measurement. To ensure the accuracy of the collected liquid amount and minimize the percentage of error, each of these samplings was repeated three times for each tower. Finally, the average moisture collected in the collector for each tower is determined.

Each column was arranged as a layered bed. The nominal design water absorption capacity of the adsorbent for activated alumina and A3 molecular sieve is approximately the same, 21 and 20% by weight, respectively. Therefore, based on the definition of absorption capacity, the amount of water removed was calculated relative to the total amount of adsorbents. As a result, the total amount of A3 molecular sieve and activated alumina was considered to be 127.50 kg. The feed gas flow rate to the dehydration unit was 1200 m^3/h under actual operating conditions. During operation, the pressure was in the range of 250-300 psi, and the gas temperature varied between 10 and 40°C. Regeneration was performed using a slipstream of the dried outlet gas, which was heated during the desorption step up to approximately 250°C. After regeneration, the outlet gas was cooled to condense the released vapors, and the resulting liquid was separated from the gas stream in a separator and collected in a liquid collector. The collected liquid contained water and organic compounds, which were separated based on density difference, with water forming the lower phase and the lighter organic phase remaining on top. The mass of each phase was measured using a balance with an accuracy of 0.1 g, and representative organic samples were analyzed by GC-MS to identify the desorbed hydrocarbon compounds.

5. Results and Discussion

5.1. Input and Output Analysis

The mass fraction of water in the inlet gas is considered one of the essential data. Given the lack of access to this data, the mass fraction of water in the inlet gas was calculated based on the operational design specifications provided by the Petroleum Industry Research Institute, using the dew point of the inlet gas, using Peng-Robinson equation of state (-13°C at 200 psig) with the Aspen HYSYS V.14 software (150-170

ppm). The mass fraction of water in the inlet gas was determined to be 0.000176. (Table 3) shows the specifications of the gas entering the station. According to ISO 15403-1:2006, the water content of CNG should be sufficiently low to prevent liquid-water and hydrate formation under the expected pressure and temperature conditions. A water content below 30 mg/m^3 is indicated as a satisfactory level. This corresponds to approximately 41 ppmv at the standard reference conditions of 15°C and 101.325 kPa (ISO 15403-1, n.d).

Table 3: Characteristics of the Feed Gas Entering the CNG Station Absorption Beds

No	Ingredients/Specifications	Value	Unit
1	Temperature	25.00	℃
2	Pressure	1.00	atm
3	Hydrogen sulfide	<1 ppm	-
4	Methyl mercaptan (odorant)	4.10	mg/m^3
5	Nitrogen	3.50	%mol
6	Methane	91.00	%mol
7	Carbon dioxide	0.80	%mol
8	Ethane	3.70	%mol
9	Propane	0.65	%mol
10	Isobutane	0.12	%mol
11	Normal butane	0.17	%mol
12	Isopentane	0.03	%mol
13	Normal pentane	0.02	%mol
14	Hexane	0.01	%mol
15	Calculated molecular weight	17.54	g/mole
16	Calculated relative density	0.61	-
17	Net calories	34.10	mJ/m^3
18	Gross caloric value	37.82	mJ/m^3
19	Wobbe index	1298	BTU/ft^3
20	Compressor outlet flow	1200	m^3/h

In (Table 3) the outlet moisture content was estimated separately based on the absorption and recovery analysis. In this study, heavy hydrocarbons absorbed were identified using GC-MS analysis. According to the report obtained from the analysis of the liquid collected during the desorption process, pentane and hexane were identified as heavy hydrocarbons in the liquid phase.

5.2. Effect of Adsorption Time

In this study, the amount of water, organic materials, and the total liquid collected from the condenser of the gas exiting the tower during the desorption phase were examined based on experimental measurements from the CNG operational unit. The subsequent analysis will focus on the amount of moles desorbed and the changes in water, organic materials, and the total liquid collected in both towers, as well as the average between the towers. Additionally, the mass fraction of water in the outlet gas was estimated during different adsorption time cycles. On the x-axis, the number outside parentheses represents adsorption time, and the number in parentheses indicates the corresponding total cycle time.

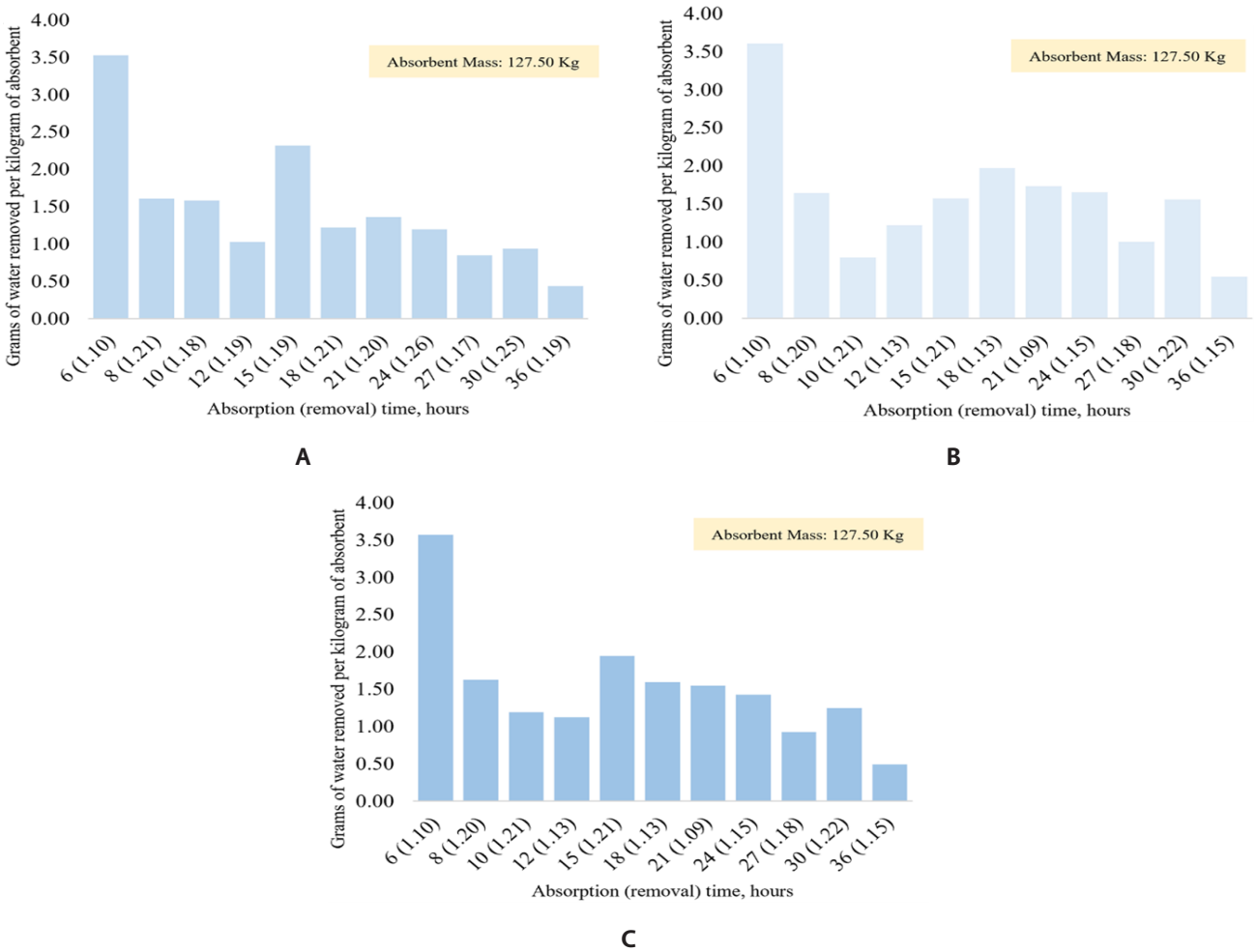


Figure 2. Amount of Desorbed Water from Adsorbent - A) Tower 1 -B) Tower 2 -C) Tower 1&2

According to (Figure 2.A), the highest amount of desorbed water in Tower 1 is 3.53 $\frac{g}{kg\ adsorbent}$, at an adsorption time of 6 h, while the lowest value is 0.44 $\frac{g}{kg\ adsorbent}$ at 36 h. As shown in (Figure 2.B), for Tower 2, the highest and lowest specific amounts of desorbed water are 3.61 and 0.55 $\frac{g}{kg\ adsorbent}$, respectively, corresponding to adsorption times of 6 and 36 h. (Figure 2.C) shows that the average values for the two towers also follow the same trend, with the highest value of 3.57 $\frac{g}{kg\ adsorbent}$ at 6 h and the lowest value of 0.49 $\frac{g}{kg\ adsorbent}$ at 36 h. (Figure 2) indicates that the specific amount of desorbed water generally decreases as the adsorption cycle time increases from 6 to 36 h. This behavior suggests that extending the

adsorption time does not improve the effective water uptake under the present operating conditions. During longer cycles, heavy hydrocarbons may be co-adsorbed together with water and gradually accumulate within the pores of the molecular sieve and activated alumina beds. This could lead to partial pore blockage, increased mass transfer resistance, and reduced accessibility of water molecules to active adsorption sites. In addition, because the regeneration period remained nearly constant for all experiments, the adsorbent bed was likely not fully regenerated after longer adsorption cycles. Consequently, the effective water adsorption capacity may have declined, resulting in lower specific water desorption at extended adsorption times. It is essential to distinguish between the measured desorbed water presented in (Figure 2) and the theoretical adsorption capacity of the molecular sieve. While the desorbed water mass provides an indication of the operational loading, it may not represent the total equilibrium capacity. This discrepancy is particularly relevant for longer cycles where incomplete regeneration might occur. In such cases, the desorbed amount reflects only the 'working capacity' the fraction of water actually removed during the heating phase rather than the total moisture captured by the adsorbent. Therefore, a decrease in desorbed water at longer cycles could be attributed to both a decline in adsorption efficiency and the accumulation of residual moisture (and organic contaminants) that was not fully removed during the previous regeneration step.

According to the control criterion established for terminating the desorption operation (Figure 3), the desorption time remained nearly constant, at approximately 70-75 min, even though the adsorption time increased from 6 to 36 h.

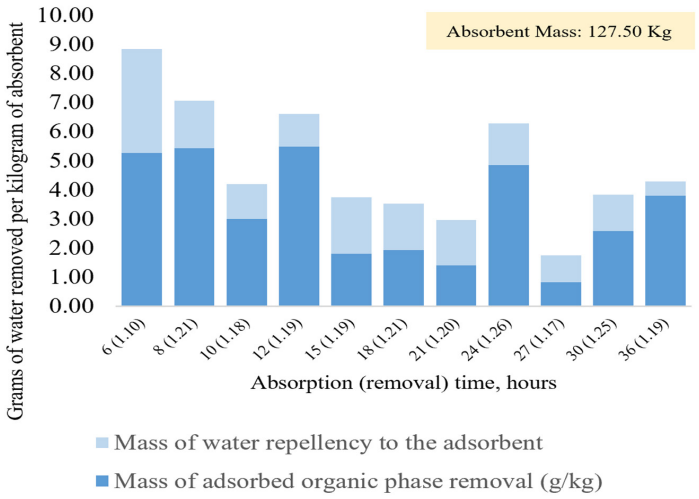


Figure. 3 Amount of Desorbed Water and Organic Materials - Average of Towers 1 and 2

The liquid collected from desorption in both (Towers 1 and 2) was averaged to evaluate the overall performance of the system. (Figure 3) shows that the highest and lowest amounts of liquid collected per kilogram of adsorbent during the examined time cycles are approximately 9 and 2 grams, corresponding to time cycles of 6 and 27 hours, respectively. The average liquid collected per kilogram of adsorbent during the 8, 12, and 24-hour time cycles is 7 grams. (Figure 4) shows the average amount of organic matter excreted. This behavior indicates that extending the adsorption period does not improve the reversible recovery of organic compounds during regeneration. In longer adsorption cycles, heavier hydrocarbons have more time to enter the porous structure of the molecular sieve and activated alumina beds and become

retained in less accessible adsorption regions. Their accumulation could potentially contribute to partial pore blockage and increased internal mass-transfer resistance. Since the regeneration time was kept constant in all experiments, the retained organic compounds may not have been completely removed from the adsorbent during the longer cycles. Consequently, the amount of organic material recovered during regeneration decreased with increasing adsorption time.

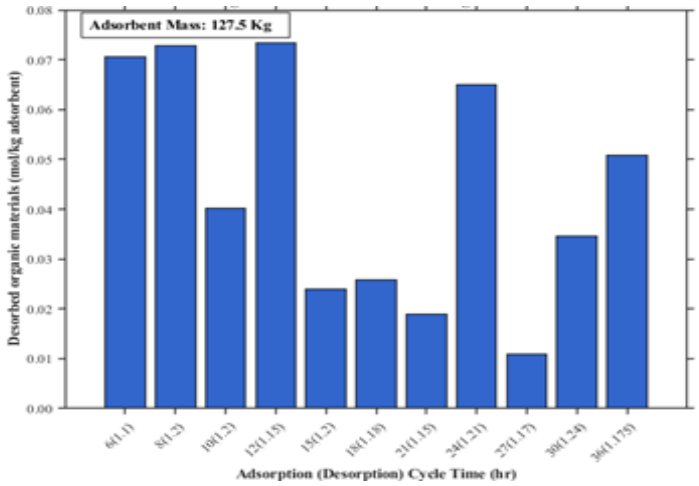


Figure 4. Moles of Organic Materials Desorbed - Average of Towers 1 and 2

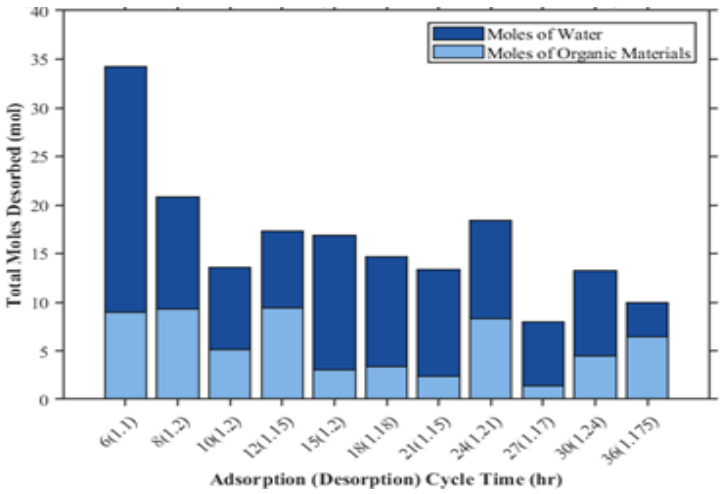


Figure 5. Comparison of Moles of Water and Organic Materials Desorbed - Average of Towers 1 and 2

As shown in (Figure 5), the highest amount of desorbed water is approximately 25 mol in the 6-hour cycle, while the lowest value is about 3.5 mol in the 36-hour cycle. For the organic fraction, relatively high values are observed at the 6-, 8-, 12-, and 24-hour cycles, whereas the lowest value, about 1.38 mol, occurs at the 27-hour cycle. The data therefore show that the behavior of the organic fraction is irregular rather than strictly monotonic. In this figure, "moles of organic materials" denotes the total estimated moles of the desorbed hydrocarbon mixture, calculated using the measured organic mass and the representative/average molecular weight derived from GC-MS analysis. Accordingly, (Figure 5) is intended to compare the desorbed amounts of water and organic components during regeneration, rather than to directly prove pore blocking or diffusion limitations. Any possible contribution of heavier hydrocarbons to fouling has therefore been discussed cautiously as a potential

interpretation, likely associated first with the activated alumina layer and then, if hydrocarbon carryover continues, with the molecular sieve layer. The moles of desorbed organic materials were estimated using the measured mass of the separated organic phase and a representative molecular weight based on the dominant hydrocarbons identified by GC-MS.

In examining the moles of water and organic materials desorbed, the smaller kinetic diameter of water molecules compared to the pore diameter of the A3 molecular sieves allows for their easy penetration into the pores of the adsorbent. Therefore, they have a high selectivity for water molecules and are very effective in water adsorption.

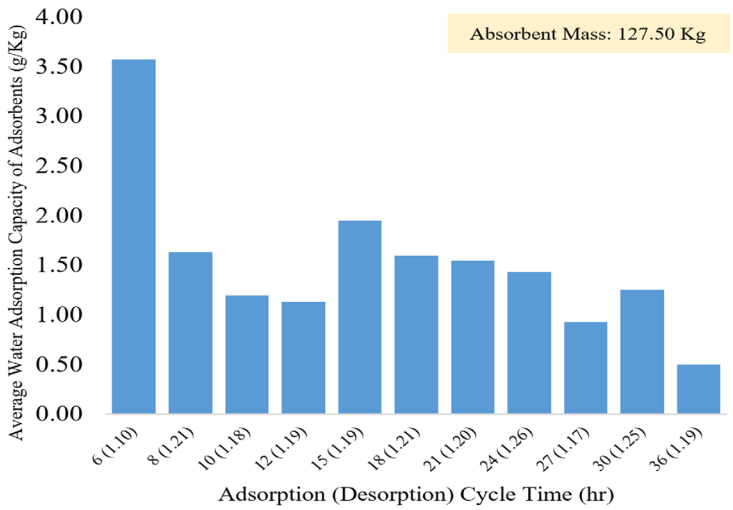


Figure 6. Average Water Adsorption Capacity of Adsorbents - Average of Towers 1 and 2

As shown in (Figure 6), the highest apparent water loading, calculated from the desorbed water, during the 6-hour cycle is of adsorbent. It is crucial to clarify that this calculated specific adsorption (3.5~g\/kg) represents the operational dynamic loading under the station's current specific conditions, rather than the thermodynamic equilibrium capacity of the Molecular Sieve A3 (which typically ranges between 15-20 wt%). This difference may suggest that the industrial adsorption beds are conservatively designed relative to the current inlet gas flow rate and moisture content. However, other factors such as incomplete regeneration, liquid-recovery inefficiencies, feed-moisture fluctuations, flow maldistribution, or competitive adsorption by organic compounds may also contribute to the relatively low apparent loading. In this study, due to the inability to measure the quality of the gas exiting the refueling nozzle, the mass fraction of water in the outlet was determined for different time cycles using a mass balance and assuming complete regeneration. The results of the analysis of the mass fraction of water in the outlet are presented in (Table 4).

Since direct measurement of the outlet-gas moisture at the refueling nozzle was not feasible, the outlet water mass fraction was estimated indirectly using a mass-balance approach. In this calculation, complete regeneration of the adsorbent bed in each cycle was adopted as a simplifying assumption. Therefore, the values presented in (Table 4) should be interpreted as approximate estimates rather than direct measurements. The inlet-gas water content was first estimated from the inlet dew point (-13 °C at 200 psig) using Aspen HYSYS, and the outlet water mass fraction was then calculated for each adsorption-cycle duration. For the 6-hour cycle, the estimated outlet water mass fraction was 0.0367 g/kg. It should be noted, however, that

the assumption of complete regeneration is less reliable for longer adsorption cycles. As indicated by the desorption results, regeneration may become incomplete under these conditions.

Table 4: Estimated Outlet-Gas Water Mass Fraction for Different Adsorption-Cycle Durations Based on Mass Balance Assuming Complete Bed Regeneration

Adsorption Time (Hours)	Mass Fraction of Water (ppm)
6	36.70
8	127.30
10	146.50
12	155.60
15	143.20
18	153.60
21	157.90
24	161.10
27	167.70
30	164.90
36	172.40

Note: Outlet water mass fractions were estimated by mass balance assuming complete regeneration in each cycle. For longer adsorption cycles, actual outlet moisture may be higher if regeneration is incomplete.

(Table 4) summarizes the calculated water mass fraction values for different adsorption-cycle times. Since direct measurement of the outlet gas quality at the refueling nozzle was not feasible, these values were obtained indirectly using a mass-balance approach. In this calculation, complete regeneration of the adsorbent bed was assumed. The inlet-gas water mass fraction was first estimated from the inlet gas dew point (-13°C at 200 psig) using Aspen HYSYS, and the outlet values were then calculated accordingly for each adsorption-cycle duration. For comparative evaluation, the calculated outlet-moisture values were assessed with reference to the moisture specification for compressed natural gas vehicle fuel as defined in ISO 15403-1 (ISO 15403-1, n.d.). Since this specification is generally expressed in terms of water dew point rather than direct moisture concentration, the calculated values were interpreted on an equivalent basis under the relevant operating conditions. Based on this assessment, the 6-hour adsorption cycle, with an estimated outlet moisture content of 36.70 ppm, was considered to satisfy the applicable moisture requirement and to provide the most favorable moisture-control performance among the operating conditions investigated. The assumption of complete bed regeneration was adopted as a practical necessity due to the lack of direct real-time moisture monitoring at the refueling nozzle. For shorter adsorption cycles (e.g., 6 and 12 h), this assumption is reasonably accurate because the desorbed water mass aligns well with the expected dynamic loading and thermal energy input during regeneration. However, for longer cycle durations (such as 24-36 h), incomplete regeneration becomes more plausible due to potential organic fouling, heavy hydrocarbon accumulation, and finite desorption heating times.

6. Conclusion

This study experimentally evaluated the dehydration efficiency of a CNG station's adsorption unit under varying operational time cycles to optimize water removal. The investigation utilized a dual-bed system packed with Molecular Sieve 3A and Activated Alumina, focusing on the impact of cycle duration on adsorption capacity. It is important to note that due to specific operational constraints and safety protocols at the industrial site, direct measurement of certain inlet parameters, such as the precise inlet gas flow rate and real-time

fluctuations in inlet moisture content, was not feasible. Consequently, these values were estimated based on mass balance calculations and standard design specifications. Despite these limitations, the results indicated a significant decline in dehydration efficiency with extended cycle times. The 6-hour adsorption cycle was identified as the optimal operating mode, achieving the highest specific water desorption (approximately 3.5 g/kg) and providing an estimated outlet moisture content below the permissible limit. A full breakthrough analysis requires continuous measurement of the outlet moisture concentration as a function of adsorption time. In the present industrial investigation, the available measurements were limited to cycle-based dehydration performance and regeneration data, including the specific desorbed water and total collected liquid after each cycle. Therefore, a rigorous breakthrough curve and the corresponding breakthrough time could not be determined from the available dataset. In contrast, extending the cycles (up to 36 hours) resulted in a marked reduction in water uptake capacity. This decline is attributed to two simultaneous mechanisms: organic fouling by co-adsorbed heavy hydrocarbons and incomplete bed regeneration. The operational data confirmed that the regeneration heating phase was fixed at approximately 70-75 minutes regardless of the adsorption duration. In longer cycles, the higher accumulation of moisture and organic compounds deep within the bed could not be fully removed during the fixed regeneration period, leaving a residual moisture 'heel' and trapped organic impurities that progressively reduced the effective working capacity. Finally, it must be acknowledged that these findings are based on a single industrial CNG station operating under specific regional and process conditions (e.g., feed gas composition, specific pressure, and local ambient temperatures in Mazandaran province). While the identified mechanisms of competitive adsorption, organic fouling, and regeneration bottlenecks are universally applicable to similar molecular sieve systems, the direct transferability of the optimal cycle time (6 hours) to other facilities should be done with caution. Variations in feed gas wetness, heavy hydrocarbon content, and bed dimensions may shift the optimal operating window, requiring site-specific adjustments.

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بررسی رطوبت‌زدایی گاز طبیعی از طریق جذب سطحی در یکی از جایگاه‌های CNG استان مازندران

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چکیـــــــده

رطوبت‌زدایی گاز طبیعی یک مرحله حیاتی در فرآیند پالایش برای تضمین کیفیت گاز طبیعی فشرده (CNG) است. این مطالعه عملکرد یک واحد رطوبت‌زدایی صنعتی در یک ایستگاه CNG در جویبار، مازندران را با استفاده از یک سیستم دو بستری پر شده با غربال مولکولی A3 و آلومینای فعال بررسی می‌کند. هدف اصلی ارزیابی تأثیر زمان‌های مختلف چرخه جذب (از ۶ تا ۳۶ ساعت) بر راندمان حذف آب، ضمن حفظ یک بازه زمانی ثابت برای احیا بود. عملکرد با اندازه‌گیری مقدار آب دفع شده و هیدروکربن‌های سنگین متراکم شده (ناخالصی‌های آلی) در طول مرحله احیا ارزیابی شد. نتایج نشان داد که راندمان جذب به‌طور قابل‌توجهی به مدت‌زمان چرخه وابسته است. حداکثر دفع ویژه آب در چرخه ۶ ساعته مشاهده شد و تقریباً ۳/۵۰ گرم آب به ازای هر کیلوگرم جاذب به دست آمد. در مقابل، افزایش چرخه به ۳۶ ساعت، حذف آب را به‌شدت به ۰/۴۹ گرم در کیلوگرم کاهش داد. تجزیه‌وتحلیل نشان داد که در طول چرخه‌های طولانی‌تر، جذب هم‌زمان هیدروکربن‌های سنگین (مانند پنتان و هگزان) منافذ جاذب را مسدود می‌کند، مقاومت در برابر انتقال جرم ایجاد می‌کند و از جذب مؤثر آب جلوگیری می‌کند. علاوه بر این، زمان ثابت بازسازی برای تمیز کردن کامل بسترهای اشباع در چرخه‌های طولانی‌تر کافی نبود. در نتیجه، برای حفظ رطوبت گاز خروجی زیر حد مجاز (کسر جرمی محاسبه شده ۳۶/۷۰ ppm)، کاهش زمان چرخه جذب به ۶ ساعت برای کاهش رسوب آلی و اطمینان از بازسازی کامل جاذب توصیه می‌شود..

واژگان کلیدی: رطوبت‌گیری گاز، جذب سطحی، غربال مولکولی A3، جایگاه CNG، گرفتگی آلی