

Commercializing a CO₂ Technology Platform for Removing Asthma Triggers from the Home

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ABSTRACT

Asthma affects more than 26 million Americans and is the most common chronic illness among children. Asthma can be triggered by household dust, which comprises various organic and inorganic particles, including allergenic proteins. Dust mites produce particularly potent triggers, with up to 30% of the population having skin test reactions to at least one dust mite species. While there are treatments for asthma attacks, all doctors emphasize avoidance of allergenic triggers in the home environment to prevent allergy and asthma symptoms.

The Triple Phase Treatment is a patented technology developed by CarboNix, LLC. (U.S. Patents 8,722,607 and 8,709,164). This treatment sprays high pressure air and fine dry ice particles into the carpets, mattresses, or upholstered materials with simultaneous vacuuming to dislodge and remove a higher level of dust than traditional vacuuming. In addition to dislodging dust, the treatment rapidly cools the substrate to $\leq -20^{\circ}\text{C}$, freezing dust mites and their larvae instantly. The subsequent sublimation of dry ice leaves all substrates dry immediately after the treatment.

The technology has been reduced to practice, and a field study performed to test the capability of the Triple Phase Treatment to alleviate allergen triggers from the indoor environment. We compared the ability of the Triple Phase Treatment to remove dust, dust mite and cat allergens from carpets and mattresses to that of high quality vacuum removal. The rate of dust removal, as well as the dust mite (*Der p 1* and *Der f 1*) and cat (*Fel d 1*) allergen removal rates were determined for the treatment group and compared to that of the vacuum control to determine effectiveness of the Triple Phase Treatment. We found that this treatment was more efficient at removing dust from carpets, and was at least as effective at removing dust mite allergens from carpets as traditional vacuuming methods.

INTRODUCTION:

Every day in America, 44,000 people experience an asthma attack. The percentage of individuals with asthma in the United States is currently 8.2% and that percentage has been increasing markedly [1], although the rate of increase of asthma incidence now seems to have leveled off. The current prevalence of doctor-diagnosed childhood asthma in the United States is estimated at 7% [2]. Children living in poor neighborhoods bear the highest burden of disease

and are four times more likely to be hospitalized for asthma as children who live in wealthy neighborhoods. Asthma is also a health disparity problem, being more prevalent amongst African Americans than amongst Caucasians. African Americans are three times more likely to die from asthma [3] and African American women have the highest asthma mortality rate of all groups, more than 2.5 times higher than Caucasian women [3].

Asthma can be triggered by a number of factors. Of specific interest is the inhalation of bioaerosols, *i.e.*, biological triggers including allergenic proteins found in airborne household dust. Bioaerosols first accumulate, and then are released from indoor reservoirs such as carpets and bedding. Common indoor allergen generators include dust mites, cockroaches, pets, and pests such as rodents. The National Survey of Lead and Allergens in Housing reveals that 84% of US homes have detectable levels of mite allergens; about half have levels sufficient to trigger allergic reactions, and a quarter of US homes have high enough allergen levels to trigger asthma attacks [4]. The highest levels of mite allergens are found in bedding and carpets [5]. Over 50% of homes have detectable levels of at least six indoor allergens, and nearly 46% had three allergens at levels capable of triggering asthma.

Clinical allergists uniformly recommend avoidance of triggers to mitigate asthma attacks. CarboNix has commercialized a home treatment service that removes a broad spectrum of respirable hazards that trigger asthma and nasal allergies. The process employs carbon dioxide as a platform. The process has unique commercial advantages in four primary aspects: (1) the process actually kills dust mites and interrupts their life cycle, (2) the process is completely dry; (3) all the major allergen repositories are treatable (carpeting, mattresses, and upholstered furniture); and (4) CarboNix uses no environmentally-harmful chemicals.

Table 1 gives a comparison of various allergen avoidance practices. The first intervention for carpets is high frequency, high intensity vacuuming, preferably with a vacuum cleaner. Vacuuming provides dry removal of surface dust and would be expected to remove a broad spectrum of indoor allergens, but it has no effect on the dust mite life cycle. Dust mites live underneath carpet and carpet backing, and inside bedding and furniture, and will continue after vacuuming to reproduce and produce allergens [6]. Steam (actually hot water) cleaning should also remove a broad spectrum of allergens, but hot water cleaning does not kill dust mites [6]. Worse, wet treatments soak the carpet and backing, creating a humid environment that is ideal for dust mites to thrive. Customers also must wait several hours for carpeting to dry.

For mattresses, bedding, and upholstered furniture, high intensity vacuuming has the same benefits and limits as vacuuming carpets (**Table 1**). The most common avoidance measure is to place dust-impermeable covers around the mattress and pillows. While this may reduce exposure, this prophylactic measure does not reduce the underlying allergen burden. Furthermore, upholstered furniture and other repositories are of course not affected. CarboNix technology provides all the advantages shown. The Triple Phase Treatment changes the trigger avoidance paradigm because it gives patients (and the doctors who advise them) the ability to remove multiple allergens, from all of the major repositories in the home (carpets, bedding, and upholstered furniture), with a single treatment. Uniquely, the CarboNix service kills dust mites and prevent re-infestation, which no other intervention can do.

Table 1: Allergen Abatement: Competitive Advantages of the Triple Phase Treatment

Treatment or Intervention	Kills active mites	Prevents mite repopulation	Removes allergenic dust	Dry process
I. Carpeting				
High intensity vacuuming	NO	NO	YES	YES
Steam carpet cleaning	NO	NO	YES	NO
CarboNix	YES	YES	YES	YES
II. Mattresses, Bedding and Upholstered Furniture				
High intensity vacuuming	NO	NO	YES	YES
Impermeable Covers	NO	NO	NO	YES
CarboNix	YES	YES	YES	YES

TECHNOLOGY COMMERCIALIZATION

The CarboNix treatment is based on U.S. Patents 8,722,607 and 8,709,164. The treatment is delivered from a service vehicle directly to the home, apartment, or office building. The demonstration service truck shown in **Figure 1** was constructed with the support of a Small Business Innovation Research from the National Institute of Environmental Health Science, of the U.S. National Institutes of Health. All equipment and consumables are mounted on the truck, as is equipment to generate compressed air and electric power.



Figure 1. CarboNix Service Vehicle

The heart of the process is a modified Coanda nozzle (**Figure 2**) that produces a cold stream dry ice powder, CO₂ gas, and air. Compressed air enters the nozzle and is directed through the annular region around the exterior surface of the nozzle [7]. The high velocity jet stream adheres to the curved exterior surface and also entrains additional air from the surroundings, producing a high volume, high velocity flow downstream of the nozzle. The modified nozzle allows a supply of liquid CO₂ to be delivered through a capillary tube coaxially inside the air

supply tube [8]. The capillary tube extends through, and just beyond, the tip of the nozzle. Liquid CO₂ expands rapidly at the tip to 1.01 MPa, producing a two-phase flow of dry ice particles mixed with gaseous CO₂. The high velocity air accelerates the two-phase CO₂ stream, producing a cold jet of gas and particles.

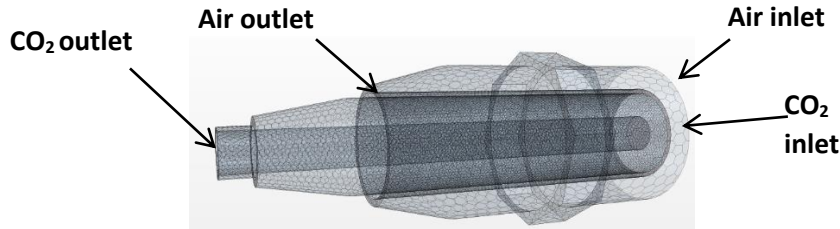


Figure 2. Modified Coanda nozzle

CarboNix developed proprietary treatment devices that use an array of nozzles to spray a uniform layer of dry ice power on the treated substrate. The cold instantly freezes dust mites, which are almost 75% water. The heavy turbulence from the CO₂ and air jet agitates the substrate and mobilizes the dust. The entire array of nozzles is surrounded by a vacuum cleaner enclosure, so the allergenic dust and gaseous CO₂ are evacuated from the indoor environment.

Figure 3 shows a schematic of the Triple Phase Treatment process. The service vehicle has a built-in air compressor and electric generator. On board the service body is a storage tank for liquid CO₂; Also on board is a CO₂ pump, and the fluid temperature, pressure, and control unit. Finally, there is a central vacuum unit on the van. CO₂, air, and vacuum are extended, via individual hoses, up to 300 feet into the home or space to be treated. CarboNix developed two detachable treatment units, one for upholstered furniture and mattresses, and one for carpets.

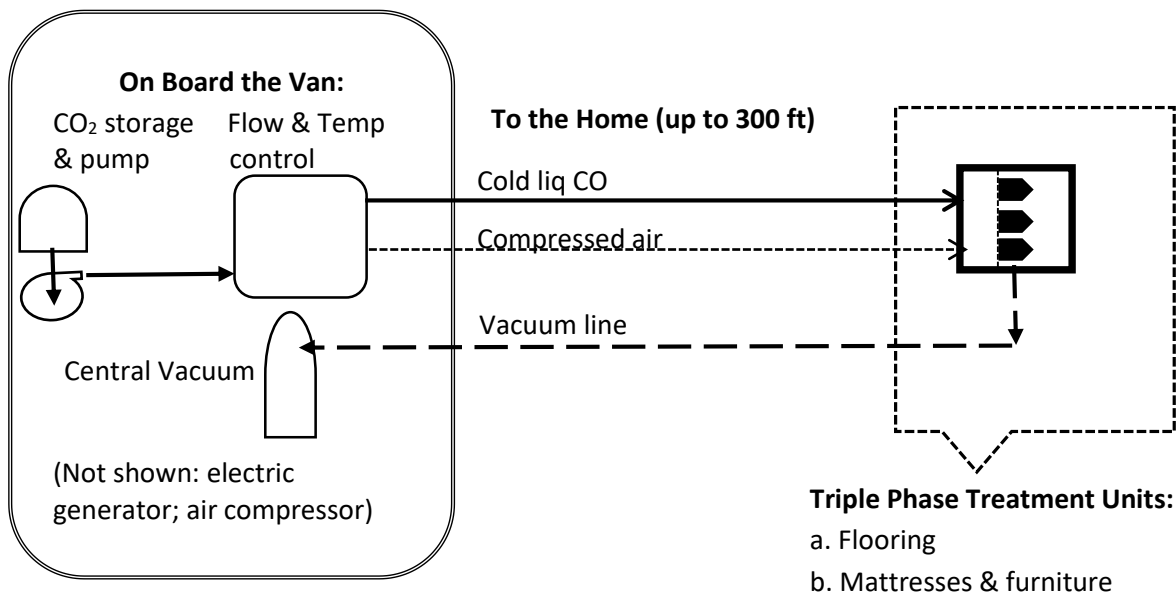


Figure 3. Schematic of the Triple Phase Process

A final, patented variation on this process involves injecting CO₂-soluble agents into the liquid CO₂ stream. We have demonstrated injection of agents such as stain removers (for cleaning) and essential oils (which act as a natural acaricide). The soluble agents mix with liquid CO₂, are deposited with the dry ice powder, and then remain after CO₂ sublimates. We term this “sublimation deposition.”

RESULTS

First we investigated stain removal on carpet that had been heavily soiled and stained by pets. While stain removal is not the public health concern, the acceptance of our abatement service is aided by customer perception of overall “cleaning”. **Figure 4** shows visual before-and-after evidence of effective cleaning performance.

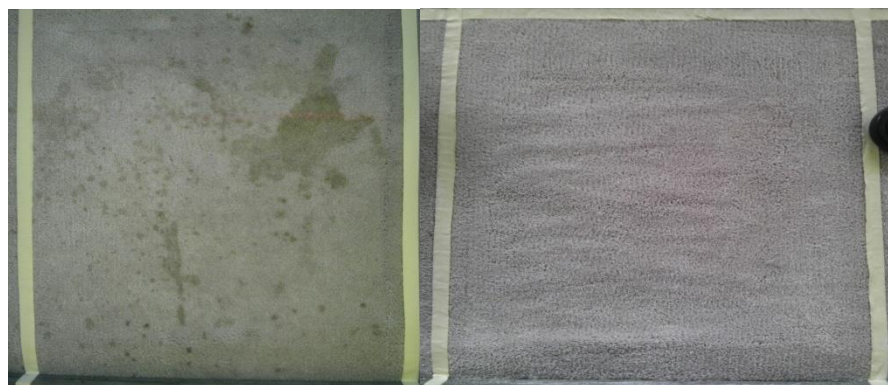


Fig. 4. Soiled carpet before (Left) and after (right) Clean Sweep® treatment

A small field study was performed to test the real-world capability of the novel Triple Phase Treatment to alleviate allergen triggers from the indoor environment. We compared the ability of the Triple Phase Treatment to remove dust, dust mite and cat allergens from carpets and mattresses to that of high quality vacuum removal. The rate of dust removal, as well as the dust mite (*Der p 1* and *Der f 1*) and cat (*Fel d 1*) allergen removal rates were determined for the treatment group and compared to that of the vacuum control to determine effectiveness of the Triple Phase Treatment.

To quantify overall dust and allergen removal, we used a hand-held vacuum to compare the amount of dust remaining on the carpet after either Triple Phase or vacuum-only treatment. A significant difference was found between Clean Sweep and ordinary vacuuming, in that there was less dust remaining on the substrate after Clean Sweep ($p = 0.0230$), implying that the process left a lower allergen load on the carpet. Allergens tend to concentrate on fine dust (diameter $< 350 \mu\text{m}$). This confirms that a primary mechanism of allergen abatement for Clean Sweep is the efficient removal of fine dust, on which allergens are adsorbed.

Variability in environmental conditions from house cleanliness and indoor climate to outdoor temperature and weather all had potential to affect the efficiency of the mobile Triple

Phase Treatment unit during individual home treatments. Despite these potential influences, the Triple Phase Treatment technology cleaned carpets at least as well as ordinary professional-quality vacuuming. Our data suggest that the Triple Phase Treatment may extract more dust from mattresses, and allergen from both carpeting and mattresses, than ordinary vacuuming alone. Further research and increased sample sizes are needed to verify this finding. Furthermore, our data suggests that the Triple Phase Treatment may reduce soiling and allergen contamination of carpets and mattress, especially for dust mite allergens. Further research is needed to verify these findings. The Triple Phase Treatment may also be more efficient at long-term remediation of dust mite allergens from carpets, as shown by a much smaller amounts of dust mite allergen at follow-up sampling compared to traditionally vacuumed control samples. The extreme cold temperatures that kill dust mites and their larvae may be attributable to this phenomenon, as it hinders the rate of re-infestation by any surviving mites that remain after traditional vacuum cleaning. Further research into specific follow-up sampling frequency and duration is necessary to verify if this effect is true.

CONCLUSION

Based on our data, the novel Triple Phase Treatment is at least as efficient as industrial vacuuming practices at removing dust from carpets and mattresses. Further work is necessary to conclusively determine if this method is more efficient at removing indoor allergens from carpets and mattresses, and whether the effects of this removal are longer-lived than traditional vacuuming. Further field studies with increased sample sizes are necessary to confirm the results of this study.

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REFERENCES

1. Akinbami, O.J., J.E. Moorman, and X. Liu, *Asthma prevalence, health care use, and mortality: United States, 2005-2009*. 2011: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics.
2. Dhar, P., et al., *Synthesis, antimicrobial evaluation, and structure–activity relationship of α -pinene derivatives*. *Journal of Agricultural and Food Chemistry*, 2014. **62**(16): p. 3548-3552.
3. (NIAID), N.I.o.A.a.I.D. *Asthma: A concern for Minority Populations, NIAID Fact sheet*. 2001; Available from: http://www.rightdiagnosis.com/artic/asthma_a_concern_for_minority_populations_niaid_fact_sheet_niaid.htm.

4. Arbes, S.J., et al., *House dust mite allergen in US beds: results from the First National Survey of Lead and Allergens in Housing*. Journal of Allergy and Clinical Immunology, 2003. **111**(2): p. 408-414.
5. Salo, P.M., et al., *Exposure to multiple indoor allergens in US homes and its relationship to asthma*. J Allergy Clin Immunol, 2008. **121**(3): p. 678-684 e2.
6. Colloff, M.J., *Dust Mites*. First ed. 2009, Collingwood Victoria: CSIRO Publishing/ Springer.
7. Lee, J.M., et al. *Effect of Coanda nozzle clearance on the flow characteristics of air amplifier*. in *2014 ISFMFE - 6th International Symposium on Fluid Machinery and Fluid Engineering, 22-25 Oct. 2014*. 2014. Stevenage, UK: IET.
8. Jackson, D.P., *Carbon dioxide snow apparatus*, U.S.Patent and Trademark Office, Editor. 2007, Cool Clean Technologies, Inc.: USA.