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Changes of Smoke Components and Smoke Odor by Far Infra-red Radiation in a Closed Room

Keon-Joong Hwang*, Moon-Soo Rhee and Do Young Ra
Korea Ginseng and Tobacco Research Institute, Taejon 305-345, Korea
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ABSTRACT : **This study was conducted to evaluate the effect of far IR radiation for the elimination of sidestream smoke components in a closed room. The measurements covered particle sizes of 13.8-542.5 nm, particle concentration, TSP, UVPM, FPM, solanesol, and the following gases and vapor components of smoke : carbon dioxide, carbon monoxide, nicotine, and 3-ethenyl-pyridine. Also, the changes of smoke odor strength by far IR radiation were tested by using the electronic nose system. There was no difference between control and far IR radiation in changes of the concentration of CO_2 and CO. The concentrations of TSP, UVPM, FPM, solanesol, nicotine, and 3-ethenylpyridine were reduced by far IR radiation. The growth and diminishing rate of RSP diameter was accelerated by far IR radiation compared with control. There was a little difference of smoke odor change with far IR radiation by electronic nose system analysis. Our results indicated that the use of far IR radiation had a little effect on changes of solid, vapor, and odor of smoke, but it had no effect on gaseous components.**

Key words : **ETS, Far infra-red radiation, IAQ, Smoke odor**

Environmental tobacco smoke (ETS) is a complex mixture and the composition of ETS changes with time and with environmental condition. ETS consists of liquid and solid particles of different sizes and of inorganic and organic gases. Many factors affect the presence and persistence of ETS in indoor air. Factors important to all constituents include the presence of materials which absorb the constituent, the presence of surfaces and reactive species from other sources, UV radiation, and the indoor temperature and humidity (Guerin et al., 1992). The composition of ETS depends upon the particular environment in which the sidestream and exhaled mainstream smoke are released. The volume of the space, the ventilation rate, carpets, furniture, etc., play an important role in determining ETS composition (Klus, 1986). As the ETS composition is diluted and mixed with the ambient air, the more volatile components of the smoke particles evaporate, and the droplets shrink somewhat in size.

Cigarette Smoke is one common indoor contaminant which is consequently very difficult to remove from the air. There are many different techniques for removing Cigarette Smoke from indoor air. Increased ventilation is most popular method to get fresh air into the room. The room air cleaners are often used for removing Cigarette Smoke from indoor air, but it is difficult to achieve effectively, both for particles and for gases. The efficiency of air cleaner includes not only efficiency, expressed in terms of count instead of mass, but also other important factors. These factors include rate of resistance buildup, dust-holding capacity, and cleanability or longevity (Plog, 1988). Infrared (IR) radiation is electroma-

* Corresponding author : *Korea Ginseng and Tobacco Research Institute, Taejon 305-345, Korea*

gnetic in origin. The IR spectral region covers the electromagnetic radiation range from about 0.75 um to 1,000 um. IR rays are invisible to the human eye. Though far IR extends from about 2 to 1,000 um, the interesting wavelength for this study encompasses from 2 to 25 um, wherein the majority of molecular vibrations of chemical significance occur, and which therefore is the most widely useful region of the IR electromagnetic spectrum (Kendall, 1990). The purpose of this study is to investigate the effect of far IR radiation on concentrations of sidestream smoke constituents and changes of cigarette smoke odor in closed indoor air.

MATERIALS AND METHOD

Experimental Conditions : Far IR radiating fluorescent lamp was tested according to its ability to change particles and gases of sidestream smoke from the atmosphere in the closed room. We assessed the efficiency of far IR radiation by monitoring the rate of decay of the concentration of the ETS. We use nine far IR fluorescent lamps with 20 W power for this experiment. The experiment was conducted 5 times with and without far IR radiating fluorescent lamps in following environmental conditions: temperature; 21 - 24 ℃, humidity; 60-65% RH, air velocity; 0.00 - 0.02 m/s. Most of the smoke in a room is originally sidestream smoke diluted in room air. So, the test was done only with sidestream smoke. The smoke was generated by natural burning of 10 CORESTA monitor cigarette CM2 in a closed room of 24.3 m^3 (3m x 3m x 2.7m). Thereafter the concentrations of the smoke components in the room were monitored for a period of 6 hours.

Analysis of Smoke Components : Carbon dioxide (CO_2), carbon monoxide (CO), and total suspended particle (TSP) concentrations were measured with, direct-reading instrument, an Auto Building Set, Kanomax 2111. The particle size, and concentration were measured with a Thermo-system Inc.(TSI) condensation particle counter 3010, electrostatic classifier 3070A, and aerosol neutralizer 3077 for particle diameters between 13.8 and 542.5 nm. Nicotine and 3-ethenylpyridine were determined by using GC analysis after ethyl acetate extraction following elution from XAD-4 resin beads. Ultraviolet absorbing particulate matter (UVPM) concentration was analyzed on a columnless HPLC with a UV detector, and 2,2',4,4'-tetrahydroxybenzophenone was used as a surrogate standard for quantitation. Fluorescing particulate matter (FPM) was determined with emission measured at 420 nm by using scopoletin as a surrogate standard. Solanesol was determined using HPLC with a 205 nm UV detector by passing Deltabond ODS column. The change of ETS odor was measured with Neotronics Scientific, e-Nose 4000.

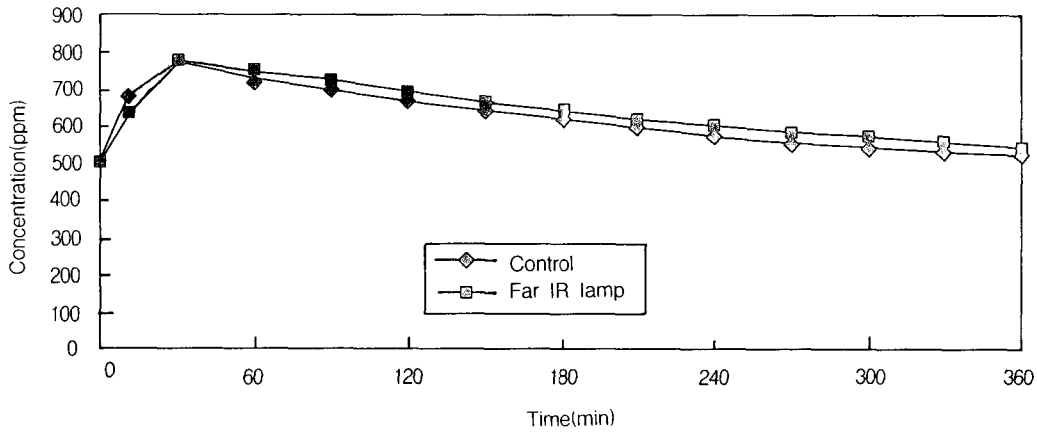


Figure 1. Changes of carbon dioxide concentration in closed room with and without far IR radiation.

RESULTS AND DISCUSSION

Changes of CO_2 and CO components by far IR radiation : ETS would be a major contributor to indoor CO_2 and CO concentrations. CO is also a commonly recognized toxin capable of being lethal at very high concentrations, of being a contributor to cardiovascular and other health effects with prolonged exposure to elevated concentrations, and possible contribution to general ill-health and discomfort associated with the sick building syndrome. Until the mid-1980s, CO was probably the most widely cited marker of ETS (Aviado, 1984). The measurement values for the CO_2 and CO concentration by time were presented in figures 1 - 2 with and without (control) far IR radiation. There was a little difference between far IR radiation treatment and control. When the use of far IR radiation, CO_2 concentration was higher, CO concentration was lower than that of control, but it was not significant by statistics. Those results indicated that the far IR radiation was not effect on reduction of CO_2 and CO components generated by sidestream of cigarette smoke.

Changes of particulate matter by far IR irradiation : Particulate matter is the most visible form of ETS components, and it is reasonably easy

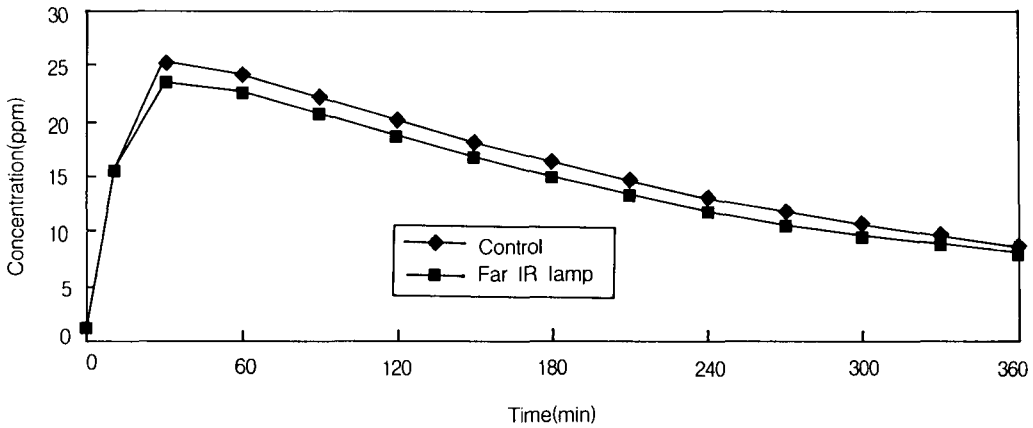


Figure 2. Changes of carbon monoxide concentration in closed room with and without far IR radiation.

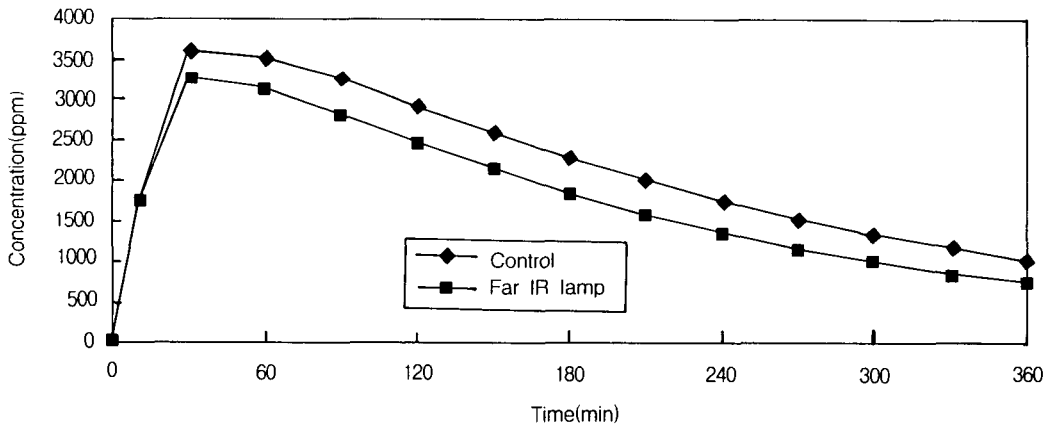


Figure 3. Changes of TSP concentration in closed room with and without far IR radiation.

to determine quantitatively with minimal instrumentation. Suspended particulate is especially important in assessing the risk to ETS exposure because ETS can be a major contributor to ambient suspended particulate concentrations and because ETS-specific particulate is somewhat related to cigarette smoke tar. TSP refers to all solid- and liquid phase matter suspended in the air and is collectable. The TSP must also be sufficiently stable to be maintained on the filter for mass determination and other analyses. Figure 3 shows the changes of TSP concentration in the room with and without far IR radiation with time. When the far IR fluorescent lamps were being used, one of the most dominant phenomena was a reduction of TSP concentration by time. The difference between far IR radiation and control was significant by statistics after 90 min sidestrean smoke generation. This result had shown that a far IR lamp radiation was able to reduce the components of sidestream smoke that exist in indoor air.

Most of the smoke particles had a size below 0.5um, and size interval between 0.1 and 0.8 um of particle volume. Therefore, most of the particle fraction of the smoke is both respirable suspended particles (RSP) and difficult to collect on filters. RSP of ETS comprises liquid or waxy droplets, although there are some data to suggest that the droplets may contain very small amounts of cigarette ash, which act as condensation nuclei (Stober et al., 1982). Figure 4 presented the size distribution of sidestream smoke and changes of particle concentration with time elapse. It is demonstrated that an initial ETS concentration in a closed room about 10 min after smoke generation had a major peak in the range between 13.8 and 542.5 nm, and then sharply decreased the number of particle after 2 hours. About 30 to 50% increase in particle size took place in the first 90 to 120 min after smoke generation and then decreased particle size for the duration of experiment. This was mostly likely due to the losses of the smaller particles through impaction on surfaces and coagulation of smaller droplets into larger ones. In case of far IR radiation, the peak of size occurred at 90 min after smoke generation, faster 30 min than control, and then decreased size distribution rapidly. This phenomenon may play a significant role in the aging of smoke by the influence of far IR radiation. These results indicated that far IR lamp radiation accelerated the coagulation of smoke particle and then settled down easily.

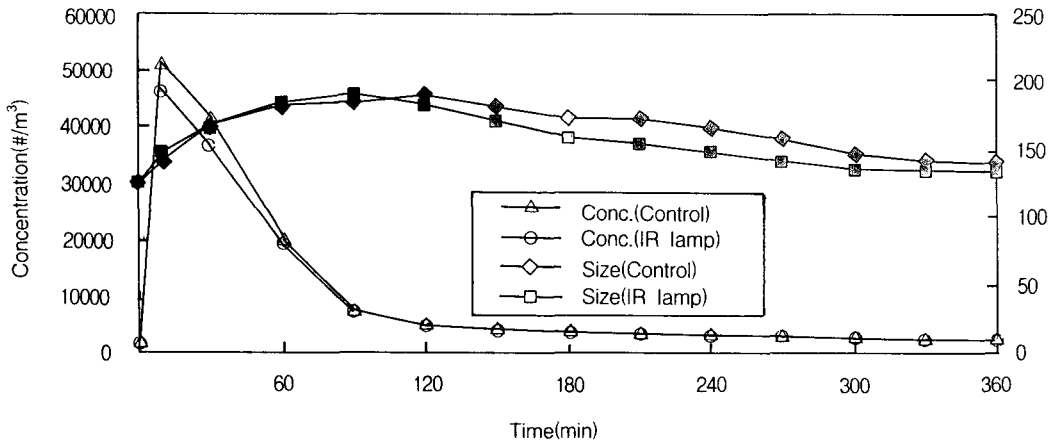


Figure 4. Changes of RSP size and concentration in closed room with and without far IR radiation.

Changes of smoke components by far IR radiation : Nicotine is unique to smoke but it ronment than does particulate matter or do the gas phase constituents of concern. Vapor phase nicotine

is probably a very good marker for smoke, especially if ventilation rates are defined and constant. Nicotine is presented in its free base form. The nicotine being presented predominantly (90-95%) in the vapor phase has some important ramifications for the ultimate relative chemical composition of ETS under field conditions (Eudy et al., 1985). Nicotine presence in the vapor phase means that it can diffuse more rapidly through the air than if it was present in the particulate phase, strike, and be adsorbed onto surfaces. Also, Eatough et al. (Eatough et al., 1989) have demonstrated that 3-ethenylpyridine is unique to tobacco smoke, is present in the vapor phase of smoke at measurable concentrations, and decays in indoor environments at rate which are much closer to those of relatively non-reactive constituents, such as CO and CO_2. Table 1 presented the changes of nicotine and 3-ethenylpyridine with and without far IR radiation by time elapse. Nicotine concentration decreased significantly, and 3-ethenylpyridine decreased somewhat, as a result of the far IR radiation. Probably one of the most significant factors to reduce nicotine was the adherence to surfaces by far IR radiation activated nicotine. This nicotine reacted chemically with other gases and particles and then condensed on particles to settle down easily. This had the effect of reducing the amounts of nicotine relative to other components in the smoke.

ETS is a combustion-derived material. It contains a number of chemical species, including single- and multiring aromatic compounds, which absorb Ultraviolet(UV) light. All UVPM is taken as ETS-derived, the measurement of UVPM would overestimate the contribution of ETS. Most investigators employing such an approach have justified it on the basis that UVPM provides a more accurate assessment of ETS derived particulate matter than the use of simple RSP levels. The fraction of RSP reported as UVPM ranges up to a maximum of 50% (Conner et al., 1990). FPM is determined with UVPM simultaneously. This method was reported to be less subject to interference than the UVPM method and would be likely to overestimate ETS contribution to RSP to a lesser extent. Perhaps the most promising marker for the particulate matter of ETS is solanesol (Ogden et al., 1989). Solanesol is trisesquiterpenoid alcohol found in tobacco leaf, cigarette smoke condensate and the RSP of smoke. Because of its high molecular weight (631 g/mole), it has very low volatility, and is expected to remain part of the particulate matter, even at high dilution. It is the RSP of ETS constituent in greatest abundance, averaging about 3-4% of the weight of the RSP collected from the ETS generated from reference cigarettes. Table 2 presented the changes of UVPM, FPM, and solanesol concentration with and without far IR radiation. When the far IR radiation was being used, the reduction rates by time elapse, in order of highest significance, were solanesol > FPM > UVPM. Approximately 20%, 15%, and 10% of solanesol, FPM, and UVPM were removed after 2 hours of far IR radiation treatment, respectively. We estimated that a far IR radiation be able to capture these types of ETS that exist in indoor air.

Table 1. Changes of nicotine and 3-ethenylpyridine concentrations by far IR radiation

Time elapse	Nicotine		3-ethenylpyridine	
(min)	Control	Far IR radiation	Control	Far IR radiation
60	422	271	135	124
120	122	80	92	78
180	80	55	77	63
240	70	51	63	55
300	58	41	49	44
360	44	36	40	36

unit : $\mu g/m^3$

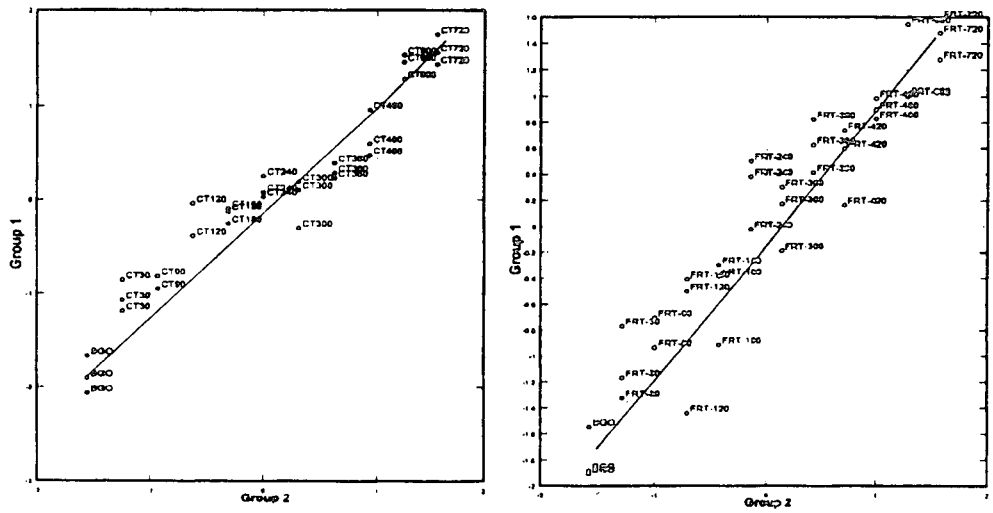
Table 2. Changes of UVPM, FPM, and solanesol concentrations with and without far IR radiation

Time elapse	UVPM		FPM		Solanesol	
	Control	Far IR radiation	Control	Far IR radiation	Control	Far IR radiation
60 min	1206	1162	1768	1711	30	20
120 min	1075	103	1521	1312	21	16
180 min	929	748	1108	946	17	13
240 min	568	495	753	611	14	10
300 min	450	397	548	443	10	8
360 min	328	309	321	243	8	7

unit : $\mu g/m^3$

Changes of smoke odor by far IR radiation : The odor of ETS is so well known, that exposure can create psychological reactions including bronchospasm and the most frequent complaints of nonsmokers about smoking is odor. The odorous compounds exhibited a stability characteristic of inactive components. The most desirable method of odor control, elimination using adsorbents or oxidants, is also the most expensive. A more common technique for odor elimination is odor modification. Counteractants that chemically alter or reduce perceived odors by allosteric inhibition do not reduce odor components (Raab, 1983). Figures 5 and 6 show the change of smoke odor with and without far IR radiation by plot of canonical variables and multiple discriminant analysis of electronic nose system. Those figures were useful to identify differences and similarities between samples. From figure 5-6, it can be seen that far IR radiation did, to some degree, change the odor of ETS. This investigation had shown that there was far IR radiation which rather effectively change odor of ETS from room air.

In conclusion, it was not easy to reduce ETS components in closed room by using far IR radiation. The solid phase, vapor phase, and odor of



(A) (B)

Figure 5. Changes of ETS odor without(A), and with(B) far IR radiation by plot of canonical variables of electronic nose system.

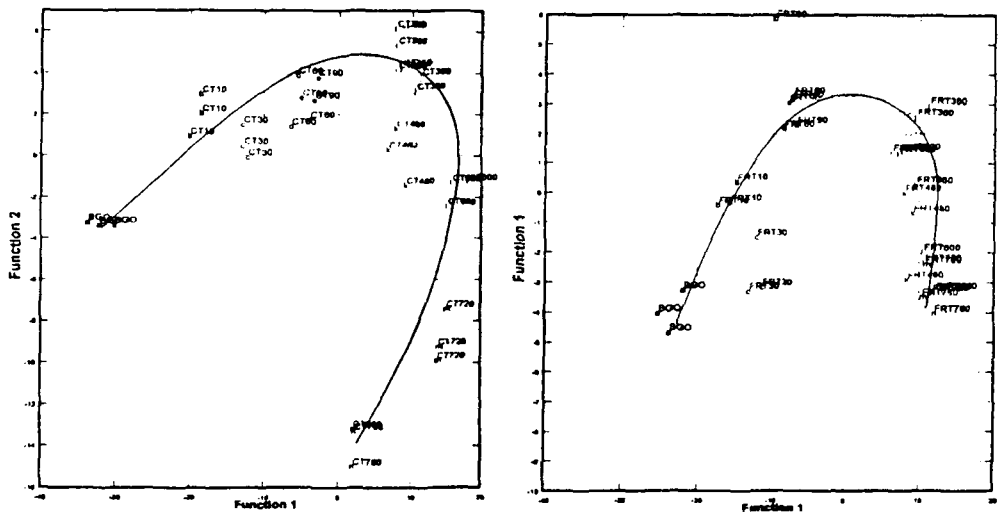


Figure 6. Changes of ETS odor without(A), and with(B) far IR radiation by multiple discriminant analysis of electronic nose system.

cigarette smoke can be reduced rather effectively, but the gaseous components were much harder to remove. Nicotine and solanesol were the dominant ETS components that was reduced from closed room by far IR radiation at a given time. It is possible to increase a little the air quality in a room with the condition that the far IR fluorescent lamp was installed and time being elapsed for the far IR induced aging of smoke.

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