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Influence of dry erase ink solvent mixtures on eye irritation

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Teaching is the process of imparting knowledge by teachers in learners. To enhance this, methods of presenting information visually to a full room of students at once are used. This includes writing on whiteboards written using whiteboard marker pens. Dry erase ink for whiteboard marker pen is composed of volatile solvent vehicle which easily vaporizes allowing the mark to dry on the surface of the whiteboard. Different manufactures use different solvents and different composition ratios in their ink brands. Different mixtures of VOCs have different irritation thresholds and potencies. This study sought to establish the components of vapour produced when different dry erase inks used in secondary schools in Nakuru County evaporate and compare their ability to elicit eye irritation on the teachers. The study design was repeated measures. Thirteen secondary schools which used whiteboards only in the classrooms were selected purposefully and the teachers in these schools were randomly selected; there were 224 respondents. Questionnaires were used to collect data on self-reported eye irritations while chromatography was used to identify the components of the vapours produced by the different brands of ink. The three ink brands used in the schools were found to contain acetone, ethanol, hexane and methanol. Inks 2 and 3 were found to have a more potent mixture than ink 1 (Odds ratio= 2.182; 95 C.I. =1.174-4.054). The study concludes that different ink solvent mixtures have different abilities to elicit eye irritation on persons exposed to their vapours (χ^2 =6.933; p=0.031) and that methanol and acetone solvent mixture (found in ink 1) were the least potent eye irritants.

Key words: Dry erase, eye irritation, secondary schools, solvents mixture, teachers.

INTRODUCTION

Traditionally, school teachers write on chalkboards written using chalk. The chalk produces a lot of dust which accumulates on surfaces and the computer machines. This has made many schools to substitute the chalkboards with whiteboards. The whiteboards or dry-erase boards came into use in the late 1980s. By the1990s most of the class rooms were replaced with whiteboards instead of blackboards (Muttappallymyalil et al., 2016).

Dry erase ink for whiteboard marker pen is composed

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of volatile solvent vehicle, binder resin, fluorinated surfactant, non-fluorinated surfactant or surfactants, including the preferred cationic amide oxide, release agent and poly(oxyalkylene) substituted colorant (Carroll and Valenti, 2000). A solvent can be defined as a liquid that has the ability to dissolve, suspend or extract other materials, without chemical change to the material or solvent (Dick, 2006). The solvent easily vaporizes allowing the mark to dry on the surface of the whiteboard (Uhara et al., 2009). In the process, these volatile organic compounds (VOCs) are released into the air and can easily get into contact with the eyes and skin of the teachers. They can also be inhaled or ingested by both the teachers and students (Halverson**,** 2011). The solvents used include butanol, diacetone alcohol, ethanol, Isopropyl alcohol, Methyl isobutyl ketone and 2-butoxy-ethanol (Halverson, 2011). Toluene and xylene are also used as solvents (Conner, 2009).

Butanol causes irritation to the eyes, skin and throat. It also causes headache, drowsiness blurred vision, photophobia (abnormal visual intolerance to light), dermatitis, auditory nerve damage, hearing loss and central nervous system depression. Diacetone alcohol causes corneal damage and also irritates the eyes, skin, nose and throat. Ethanol causes lassitude (weakness, exhaustion), drowsiness, headache and is also an irritant to the eyes, skin and nose. Isopropyl alcohol (rubbing alcohol) may cause dizziness, headache and drowsiness as well as irritate the nose, eyes and throat. Methyl isobutyl ketone irritates the eyes, mucous membrane and the skin when it comes into contact with it. It may also cause headache, narcosis, dermatitis and coma if the exposure is high. Monobutyl ether (2-butoxy-ethanol) causes eyes, skin, nose and throat irritation, destruction of red blood cells, central nervous system depression, headache and vomiting. It may also result in blood in the urine (Halverson, 2011).

Health effects of xylene are determined by the dose, duration and route of exposure (ATSDR, 2007). Short-term exposure of people to high levels of xylene can cause irritation of the skin, eyes, nose, and throat, difficulty in breathing, impaired function of the lungs, delayed response to a visual stimulus, impaired memory, stomach discomfort and possible changes in the liver and kidneys. Both short and long-term exposure to high concentrations of xylene can also cause a number of effects on the nervous system, such as headaches, lack of muscle coordination, dizziness, confusion, and changes in one's sense of balance. It can also cause death (Kandyala et al., 2010). Low to moderate levels of toluene can cause tiredness, confusion, weakness, drunken- type actions, memory loss, nausea, and loss of appetite. Long-term exposure to toluene in the workplace may cause some hearing and color vision loss while repeatedly breathing in toluene may permanently damage the brain (ATSDR, 2015). Marker pen inks with alcohol as a solvent are characterized with low odour unlike the toluene and xylene solvents which have strong odour (ATSDR, 2007). The manufacturers of the alcohol based marker pen inks label their products as non-toxic although they are irritants (ATSDR, 2015).

The irritants found in the schools as a workplace for the teachers can be controlled using the hierarchy or preferred order. This hierarchy suggests that the source should be eliminated if possible. This is the most effective control measure. Substitution is considered next where the source of irritant can be substituted with one that has no health effects. Isolation is the next considered where barriers or screens are installed for separating the teacher from a source of irritant. Administrative control can also be used which involves introduction of work practices that reduce the risk. These may include limiting the amount of time a teacher is exposed to the particular irritant. Personal protective equipment is considered when the other control methods fail. These may include the use of gloves, barriers and facemasks, to prevent contact with the irritant (Tyrer and Lee 1985; Quinlan and Bohle, 1998). It is therefore important to identify the solvents in the inks used in secondary schools and establish their potency in causing irritation on the eyes of the teachers. This can act as a guide in the selection of the most effective control method of the irritants in the different marker pens to ensure occupational safety of the secondary school teachers.

The objectives of the study were i) to identify the different brands of dry erase used in the secondary schools in Nakuru County in Kenya; ii) to establish the components of vapour produced by the different dry erase brands and iii) to compare the relative eye irritation potencies of the different brands of dry erase ink.

MATERIALS AND METHODS

The research design was repeated measure design. The study limited itself to the thirteen schools in Nakuru County in Kenya which used whiteboards in the classrooms only. Teachers in the selected schools were randomly and proportionately selected giving a total of 224 teachers. The observations were carried out at two different times. During the first time of the study, all the schools were doing their end term examination (July 2016) and therefore the teachers were not using the whiteboard marker pens because there was no teaching going on. The second observation was done during another term (February 2017) at a time when teaching was going on in all the selected schools. All the teachers were therefore using the whiteboard marker pen ink. The data on self-reported information on eye irritation of the teachers were collected using a questionnaire.

A sample of each ink brand was placed in an evacuated tube using a syringe. The ink was warmed in water bath at 60°C for 20 min to allow the headspace to reach equilibrium as used by Portari et al. (2008). The headspace vapours were then sucked using a syringe and dissolved in acetone, hexane and ethanol solvents. Chromatography was then carried out on these solutions using an Agilent technologies 7820A gas chromatography machine with a

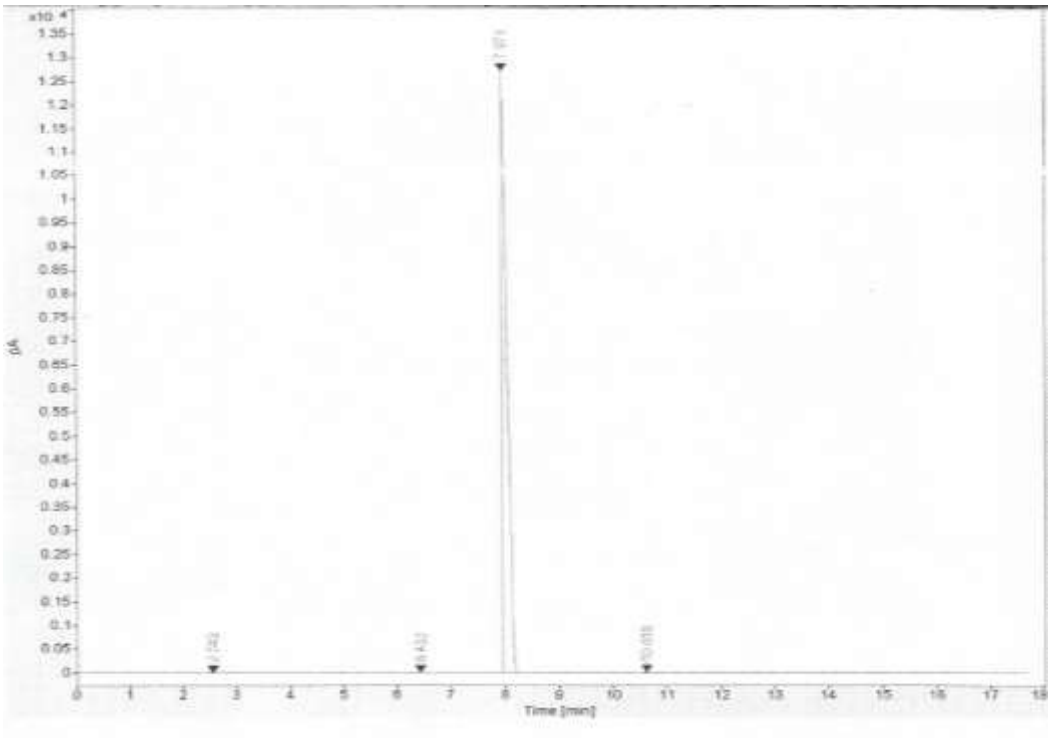

Figure 1. Ink 1 vapour in acetone.

DB 624 column of a length of 30 m, an internal diameter (ID) of 320 µm and a film thickness (DF) of 1.8 µm. The temperatures at the injection, detector and column were 250, 200 and 60 -150°C respectively. The airflow rates of oxygen, hydrogen and nitrogen were 400, 40 and 45 ml/min, respectively**.** The split ratio used was 100:1. The column temperature program started at 60.0°C for 2.00 min and was then ramped at 6.0°C per minute until 150°C was obtained. The area under the curve on the chromatogram of each of the components was used to determine the percentage composition of the components in the ink vapour.

Data were managed using SPSS (Version 23.0 for Windows) and analyzed using descriptive and inferential statistics. Tables and charts were used to represent data. One way ANOVA was used to compare the incidences of eye irritation of teachers who used the different brands of ink. Chi square was used to test the association between ink brands and eye irritation while ANOVA for repeated measures was used to compare the incidence of eye irritation of teachers during the different times of exposure. The Odds ratio was used to compare the ability of the different ink brands to cause eye irritation.

RESULTS AND DISCUSSION

Dry erase brands used in the secondary schools

The results show that there were three different brands of ink used in the secondary schools in Nakuru County. These were ink 1, ink 2 and ink 3. Seven schools used ink 1, three schools used ink 2 and the other schools used ink 3.

Components of the ink vapour

The results indicate that the vapour from ink 1 had methanol and acetone. The vapour of ink 2 had acetone and hexane while the vapour of ink 3 had ethanol and hexane (Figures 1-13). These components easily evaporated from the ink when placed in a water bath at 60^{o}C. This means that these components have a low boiling point and easily evaporate at the normal classroom temperature. Uhara et al. (2009), Cantú (2012) and Cantú (2015) say that when ink writings are exposed to the air, the solvents in them evaporate and this makes the writing to dry. In the process, they contaminate the classroom indoor air.

These result findings agree with research study carried out by Anderson and Anderson (2003) who carried out gas chromatography on emissions of felt pens and whiteboard cleaners. He found that they contained a mixture of alcohols, acetates and ketones. Castorina et al. (2016) measured emission rates of VOCs of different markers under controlled laboratory conditions and found that alcohols were the most highly emitted class of VOCs from dry erase markers.

The percentage composition of the components in the

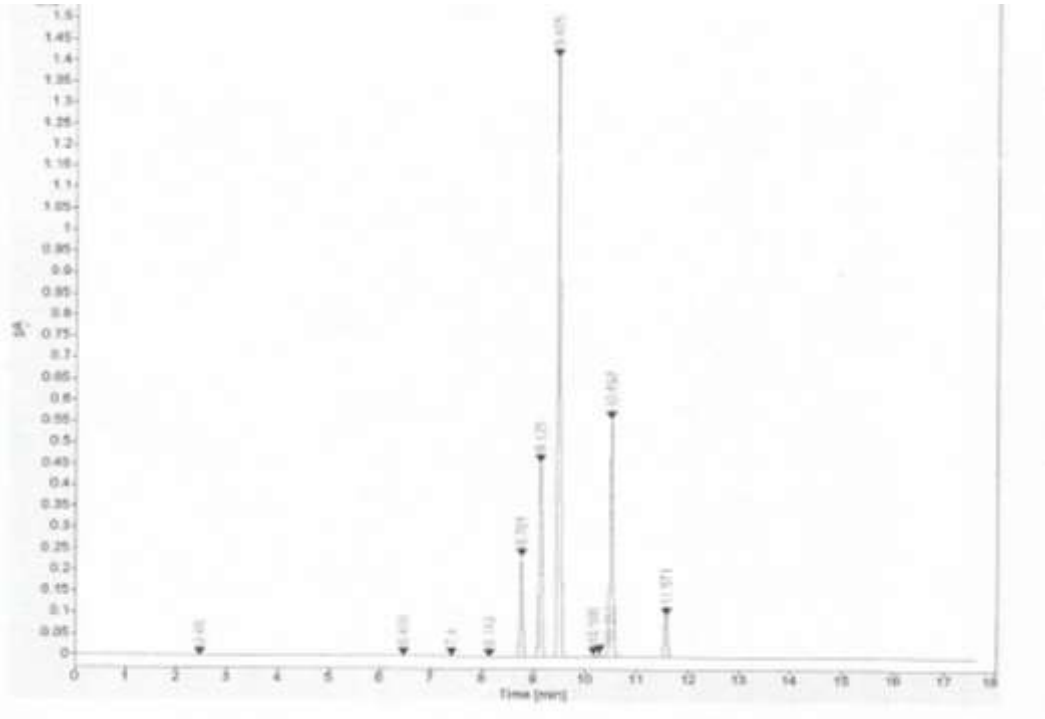

Figure 2. Ink 1 vapour in hexane.

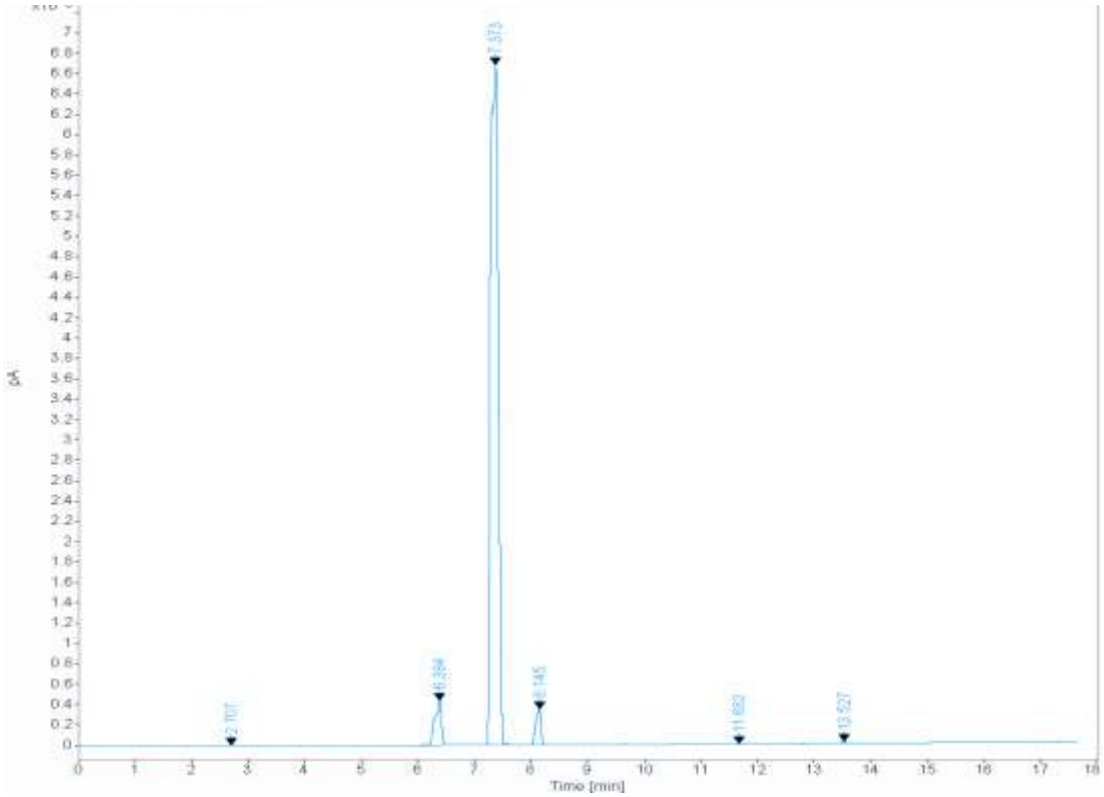

Figure 3. Ink 1 vapour in ethanol.

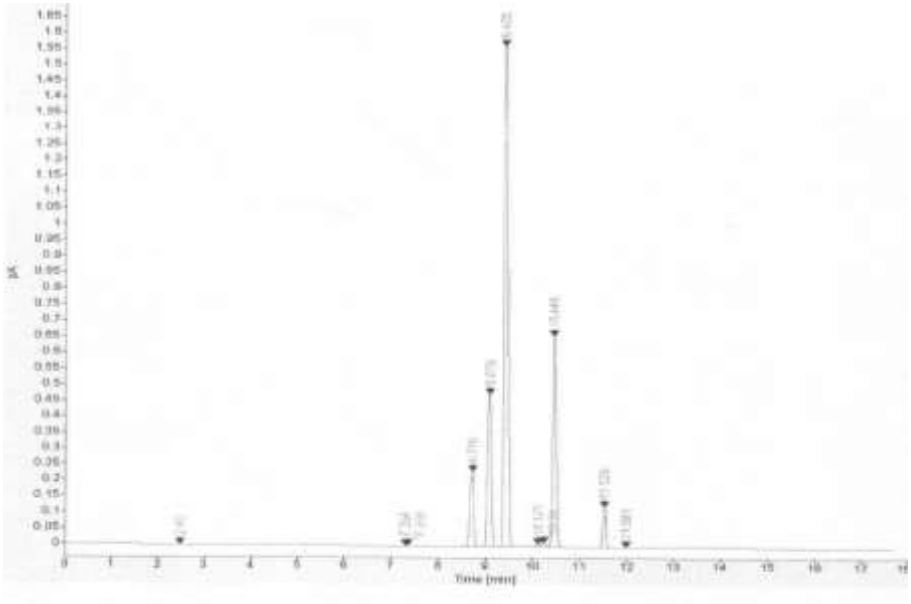

Figure 4. Hexane.

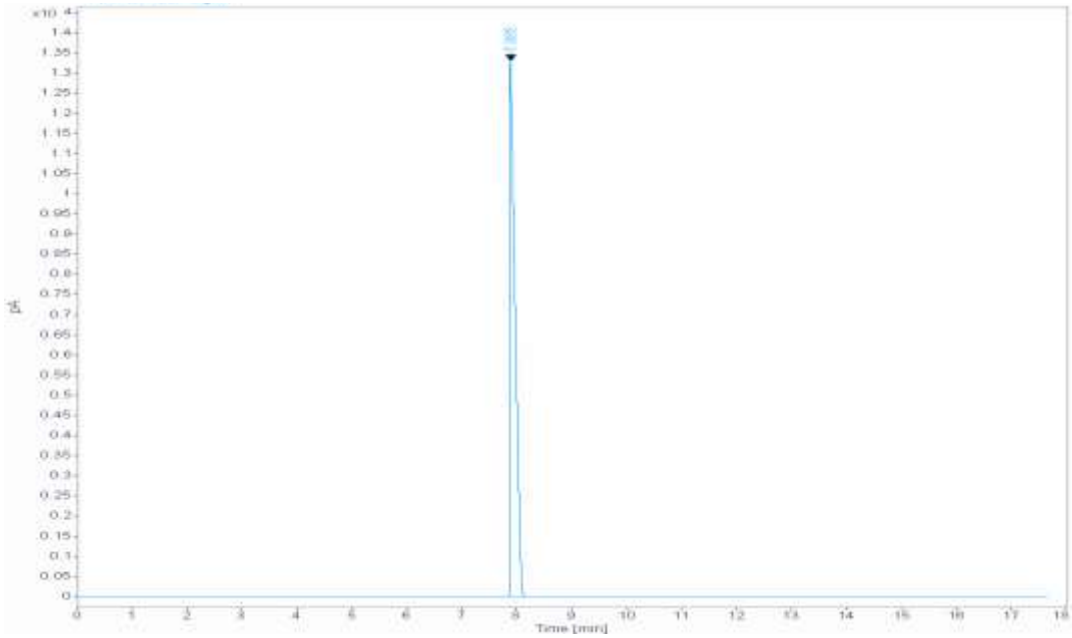

Figure 5. Acetone.

ink vapour was calculated based on the area under the curve for each component. The results indicate that the quantities of the different solvents in each of the ink were different with ink 1 having more methanol than acetone. Ink 2 had more acetone than hexane while ink 3 had a very high percentage of hexane (Table 1).

Influence of dry erase vapour on development of eye irritation

The incidence of eye irritation was higher among teacher when the marker pen ink was in use (27.1%) than when it was not in use (21.4%) (Figure 14). Whiteboard marker

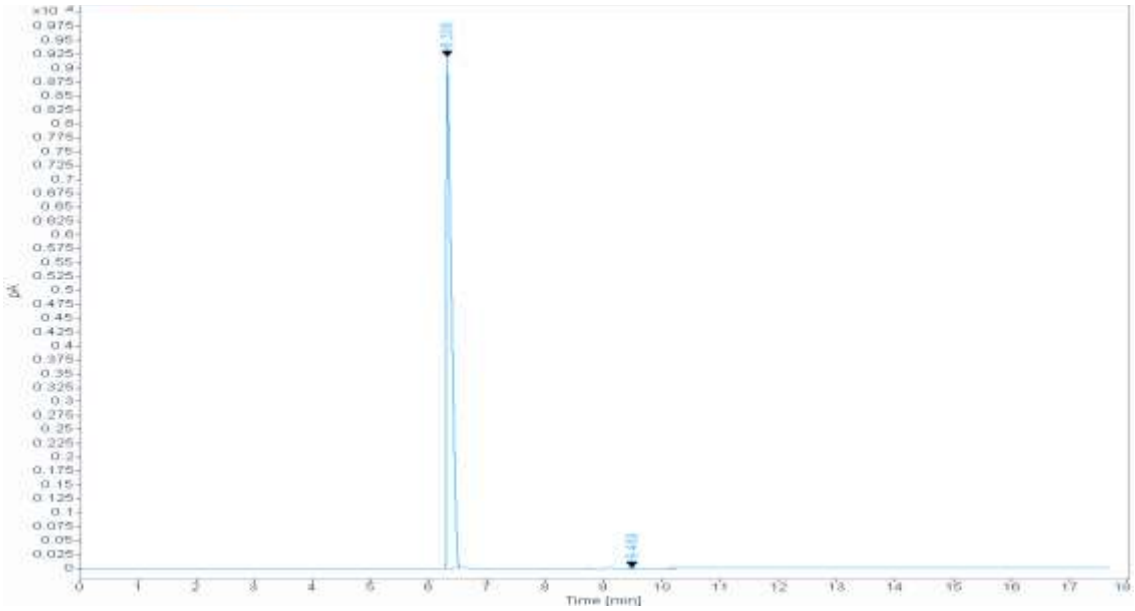

Figure 6. Methanol.

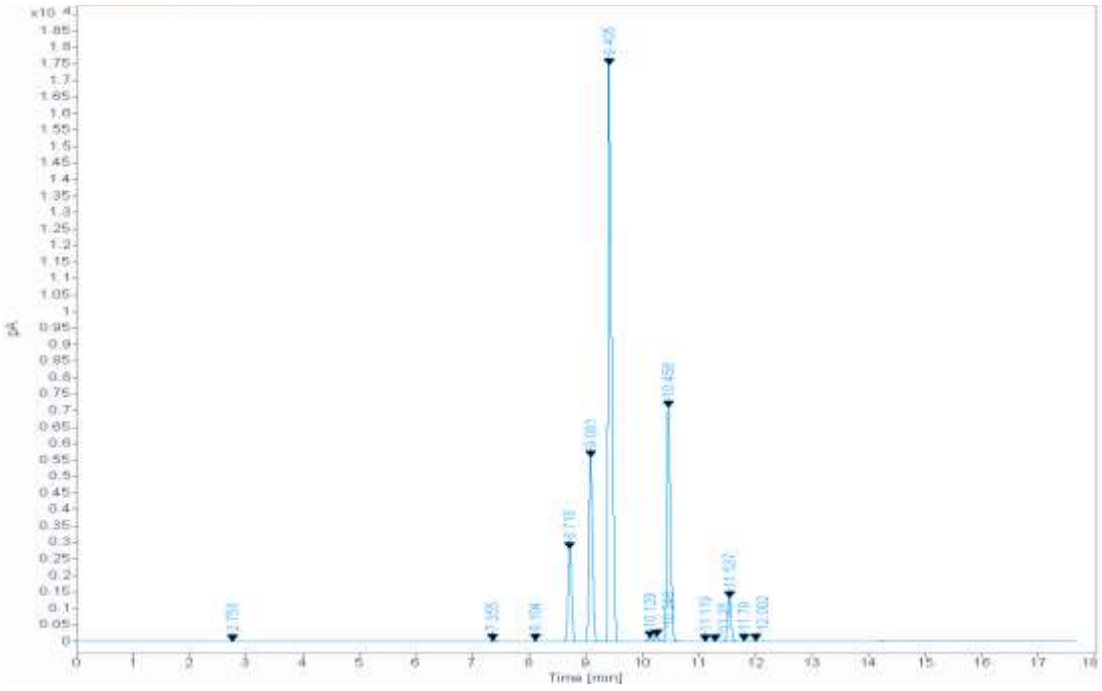

Figure 7. Ink 2 vapour in hexane.

pen ink was not used during July 2016 observation because the students were doing their end term examination. However, Whiteboard marker pen ink was in use during the February (2017) observation because teaching was going on in all the schools.

These findings agree with ATSDR (2015) who say that the components of dry erase ink are irritants. However, the difference in incidences of eye irritation between the different exposure status was not significant because seasonal factors acted as confounders (p=0.164) (Table

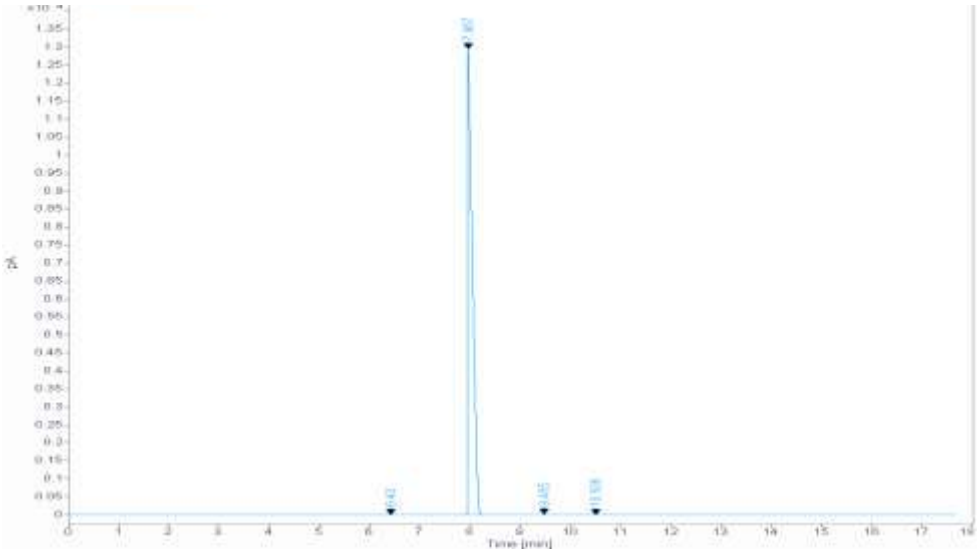

Figure 8. Ink 2 vapour in acetone.

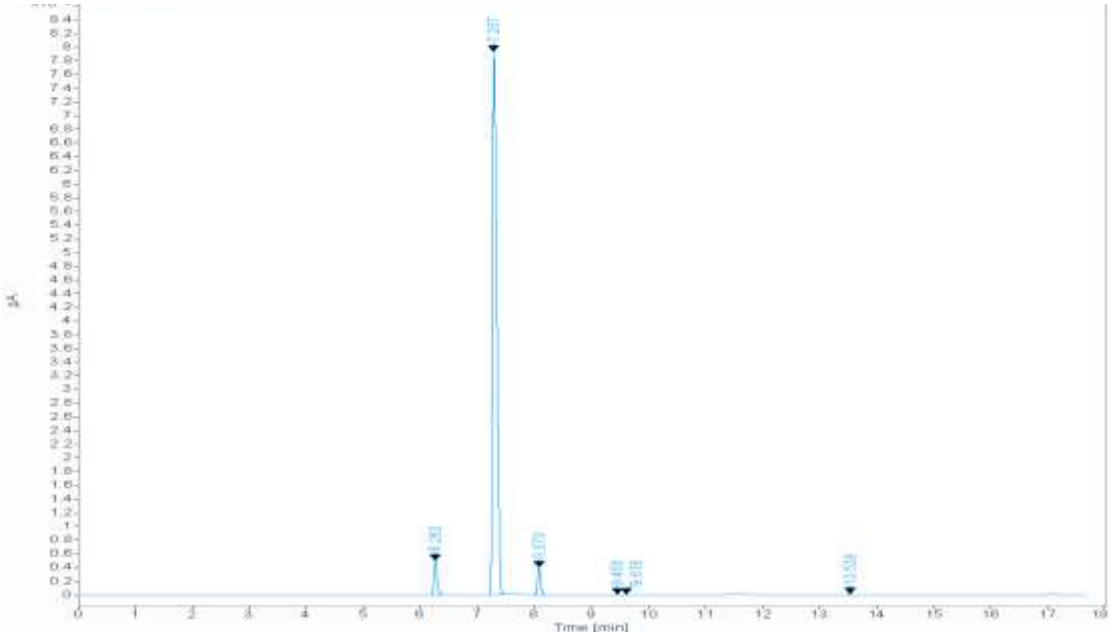

Figure 9. Ink 2 vapour in ethanol.

2).

When the incidences of eye irritation among the teachers who used the three different brands of whiteboard marker inks were compared, the difference was not significant during the non-exposure time of observation (F=1.342; p=.265) (Table 3).

The percentage incidence of eye irritation was different among the teachers who used different brands of whiteboard marker pen ink during the time when the whiteboard marker pen inks were in use. Teachers who used ink 3 had the highest incidences of eye irritation while those who used ink 1 had the lowest incidences of eye irritation (Figure 15) Statistical testing showed that there was a significant association between the brand of ink and the development of eye irritation among the teachers during the use of the ink (χ^2 =6.933; p=0.031)

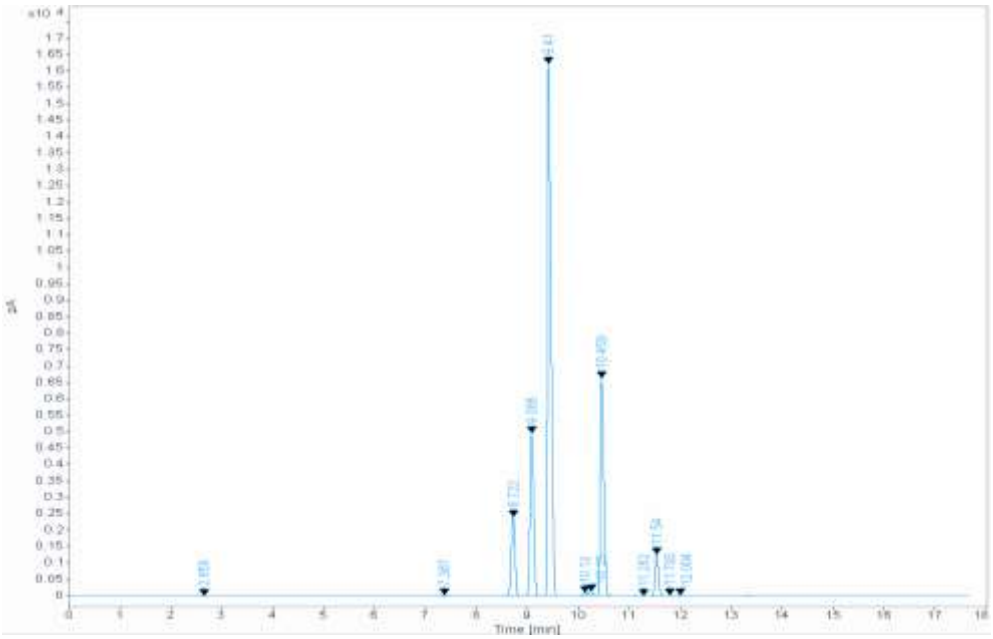

Figure 10. Ink 3 vapour in hexane.

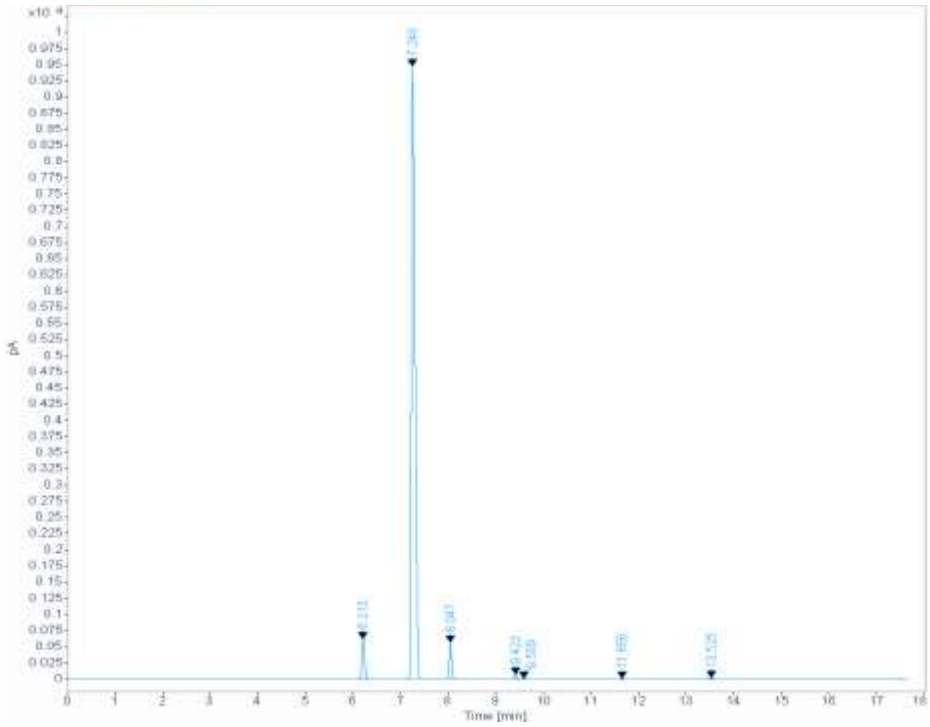

Figure 11. Ink 3 vapour in ethanol.

(Table 4).

Increase in incidence of eye irritation when the ink was in use and the existence of a significant difference in incidences between the teachers who used different brands of ink is an indication that the whiteboard marker pen ink causes eye irritation. These findings agree with

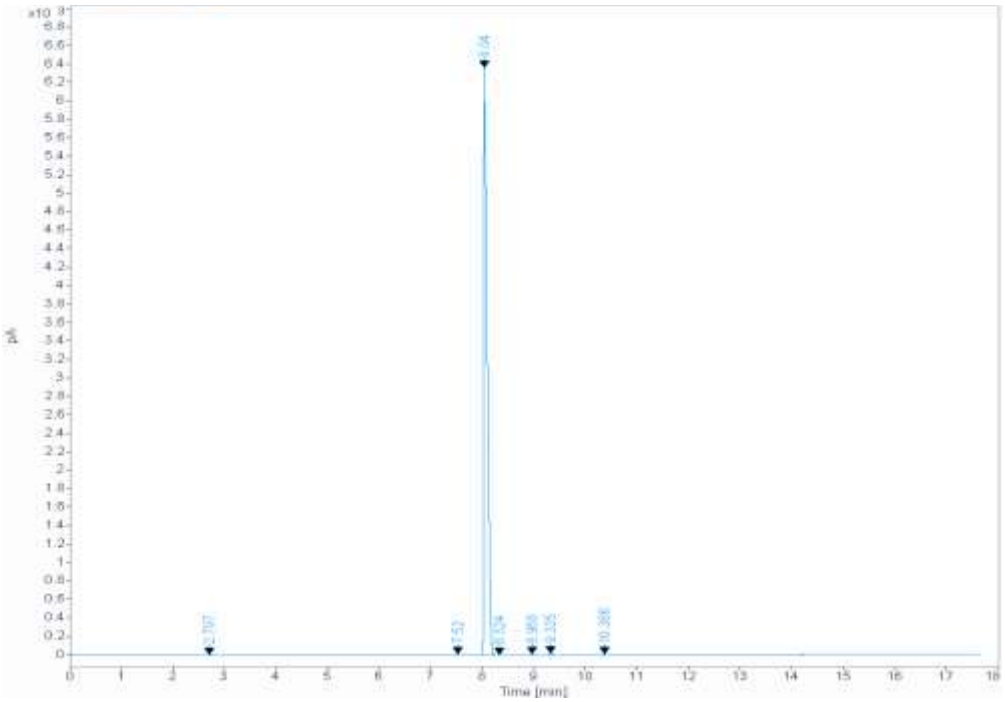

Figure 12. Ink3vapourinacetone.

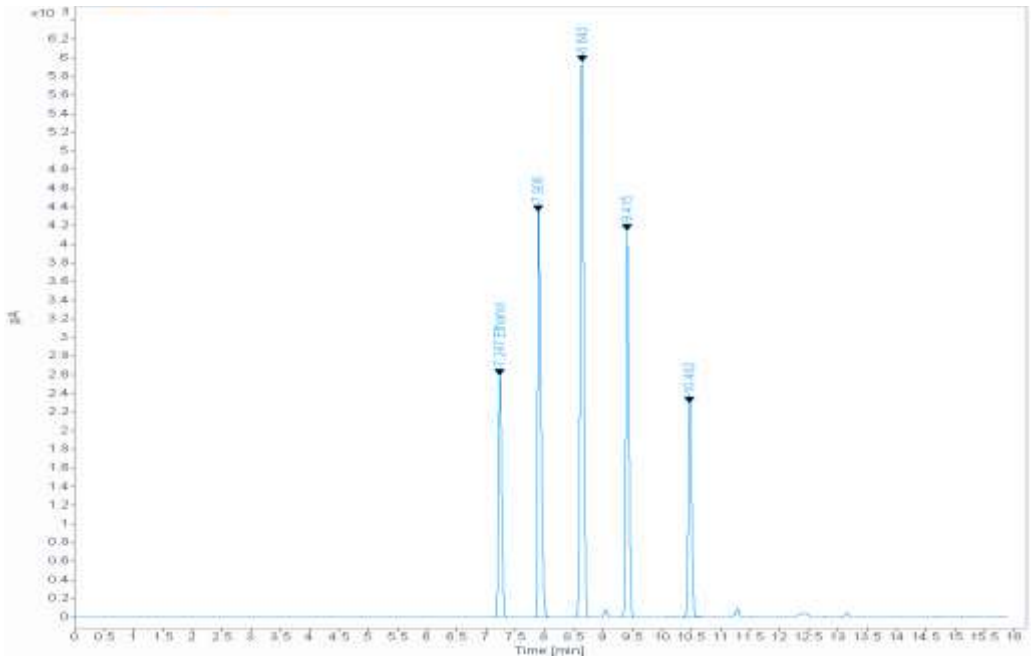

Figure 13. Ethanol and other solvents.

several authors (Mendicino, 2000; Maurer et al., 2001; Anderson and Anderson, 2003; Greenberg et al., 2003; Hathaway and Proctor, 2004; Agyeman and Himmelberger, 2009; Halverson, 2011; Battersby, 2011; Roelofs and Do, 2012; ATSDR, 2015) who found the components of dry erase ink to be irritants.

Table 1. Percentage composition of ink vapour.

Solvent		Acetone	Hexane	Methanol	Ethanol	Total
% of solvent in the ink vapour	Ink1	40		57.9		97.9
	Ink2	50.1	49.9			100
	Ink3		73.8		26.2	100

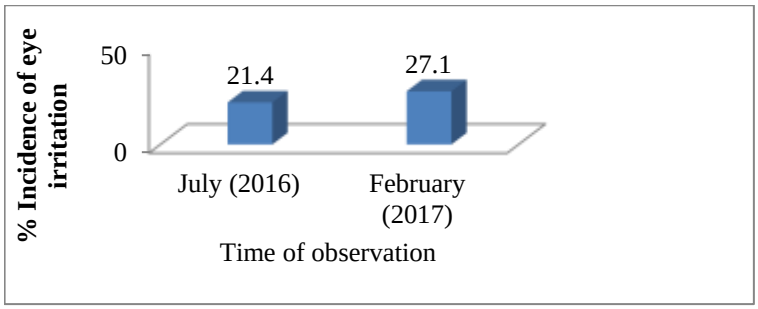

Figure 14. Influence of dry erase vapour on development of eye irritation.

Table 2. Comparison of incidences of eye irritation during exposure and non-exposure times of observation.

Source	Factor	Type III Sum of Squares	df	Mean Square	F	Sig.
Factor	Linear	0.369	1	0.369	1.955	0.164
Error(factor)	Linear	36.631	194	0.189		

Table 3. Incidences of eye irritation among teachers during non-exposure to ink.

Parameter	Sum of Squares	df	Mean Square	F	Sig.
Exposure and non-exposure times	0.436	2	0.218	1.342	0.265
Eye irritation incidences	19.483	120	0.162		
Total	19.919	122			

Post hoc test was carried out to establish which of the significantly different. The statistical test (one way ANOVA) showed that there was no significant difference between the ink 2(acetone and hexane) and 3(ethanol and hexane) (p=0.435) (Table 5).

The odds ratio of developing eye irritation by teachers using ink 2(acetone and hexane) and ink 3(ethanol and hexane) was compared with that of those who used ink 1(acetone and methanol) because ink 2 and 3 were found not to be significantly different. The results showed that the odds of developing eye irritation by a teacher using ink 2 or 3 was significantly higher than the odds of developing eye irritation by a teacher using ink 1(Odds ratio= 2.182 ; 95 C.I.=1.174-4.054) (Table 6).

The mixture of methanol and acetone had the lowest potency of eliciting eye irritation while those mixtures that had hexane had a high potency. This agree with Ernstgård et al. (2005) who did not find significant irritation from methanol vapour in their study on the disposition of methanol vapor in humans. Maurer et al. (2001) found that acetone is associated with mild irritation while Cometto-Muñiz et al. (2006) found that hexane vapour caused chemesthetic stimulation resulting in sharp eye irritation. Oh et al. (2013) found that dry eye syndrome, which is associated with ocular inflammation or eye irritation is more prevalent among those exposed

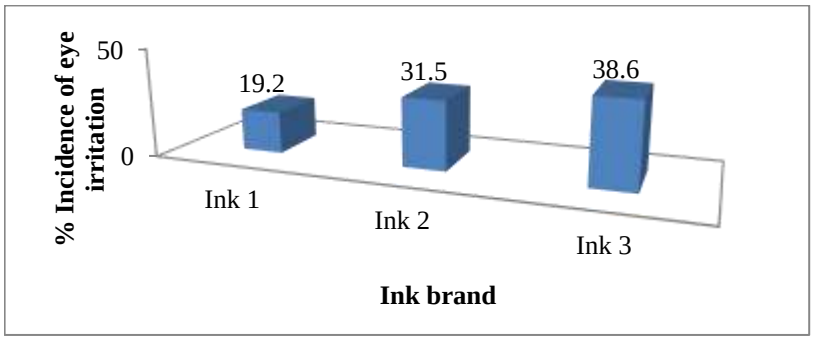

Figure 15. Incidences of eye irritation among teachers using different brands of dry erase ink.

Table 4. Association between ink brand and eye irritation.

Parameter	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	6.933	2	0.031
Likelihood Ratio	6.951	2	0.031
Linear-by-Linear Association	6.749	1	0.009
N of Valid Cases	221		

Table 5. Comparison of incidences of eye irritation between those who used ink 2 and ink 3.

Parameter	Sum of Squares	df	Mean Square	F	Sig.
Ink brand	0.140	1	0.140	0.613	0.435
Eye irritation incidence	26.185	115	0.228		
Total	26.325	116			

Table 6. Risk Estimate for those who use ink 2 or 3.

Parameter	Value	95% Confidence Interval	
		Lower	Upper
Odds Ratio for inks for odds ratio test (ink 2 or ink 3 / ink 1)	2.182	1.174	4.054
For cohort whether eyes feel irritated = yes	1.778	1.114	2.837
For cohort whether eyes feel irritated = no	.815	.694	.957
N of Valid Cases	221		

to ethanol. Different VOCs also react differently with air and other pollutants in the indoor air resulting in different mixtures which have different health effects (EPA, 2018). Capello and Gaddi (2018) say that groups of VOCs are more potent irritants than the individual VOCs. A mixture is therefore different from the sum addition of its components. The inks may therefore have shared some individual components (both ink 1 and ink 2 had acetone) but each had a different composition of VOCs in the mixture (ink 1 had acetone and methanol while ink 2 had acetone and hexane) explaining the differences in their ability to cause eye irritation. This means that teachers

who use the dry erase with methanol and acetone mixture are safer than their counterparts who use dry erase inks with hexane and acetone or hexane and ethanol mixtures. These findings also indicate that substitution method can be used to control these irritants. Substituting inks 2 and 3 with ink 1 can aid in the control of eye irritation.

Conclusion

The vapour from ink 1 had methanol and acetone, vapour of ink 2 had acetone and hexane while the vapour of ink 3 had ethanol and hexane. The different ink solvent mixtures have different abilities to elicit eye irritation on persons exposed to their vapours (χ^2 =6.933; p=0.031) and that mixtures of ethanol and hexane as well as acetone and hexane were more potent eye irritants than the mixture of methanol and acetone (Odds ratio= 2.182; 95 C.I. =1.174-4.054). Therefore substituting inks 2 and 3 with ink 1 would reduce the risk of eye irritation.

RECOMMENDATION

More research is required to establish the potency of other marker pen ink brands so that teachers can choose the marker pen ink brand that has the lowest potency to improve their occupational health and safety. The schools can meanwhile substitute the use of inks 2 and 3 with ink 1 to reduce the risk of eye irritation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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