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Chemical Risk Evaluation: A Case Study in an Automotive Air Conditioner Production Facility

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Abstract

There has been limited knowledge on worker's exposure to chemicals used in the automotive industries. The purpose of this study is to assess chemical risk and to determine the adequacy of the existing control measures to reduce chemical exposure. A cross sectional survey was conducted in a factory involving installation and servicing of automotive air conditioner units. Qualitative exposure assessment was carried out following the Malaysian Chemical Health Risk Assessment Manual (CHRA). There were 180 employees, 156 workers worked in the production line, which constitutes six work units Tube fin pressed, Brazing, Welding, Final assembly, Piping and Kit II. From the chemical risk evaluation for each work unit, 26 chemical compounds were used. Most of the chemicals were irritants (eye and skin) and some were asphyxiants and sensitizers. Based on the work assignment, 93 out of 180 (51.67%) of the workers were exposed to chemicals. The highest numbers of workers exposed to chemicals were from the Brazing section (22.22%) while the Final Assembly section was the lowest (1.67%). Health survey among the workers showed occurrence of eye irritation, skin irritation, and respiratory irritation, symptoms usually associated with chemical exposure. Using a risk rating matrix, several work process were identified as having 'significant risk'. For these areas, the workers are at risk of adverse health effects since chemical exposure is not adequately controlled. This study recommends corrective actions be taken in order to control the level of exposure and to provide a safe work environment for workers.

Keywords: chemical exposure; risk assessment; automotive air conditioner; qualitative exposure

1. Introduction

In the automotive air conditioner manufacturing, workers are constantly exposed to cocktails of solvents, additives and lubricants that can be potentially dangerous to the environment and their health. Chemicals also include flammable and explosive substances which have the potential of causing industrial disasters with subsequent dramatic effects on the workers, the public and the environment. The chemicals used in this industry contain several irritants or asphyxiants such as polyol ester lubricant, tetrafluoroethane, and tripolyphosphate. In poorly ventilated work areas, exposure to these asphyxiants can cause dizziness and induce vomiting. Studies carried out in the art restoration shops showed that engineering controls such as local exhaust ventilation are inadequate thereby leading to increased exposure to airborne chemicals (Gherardi *et al*., 2007). Long term exposure to irritants, such as solvents and dust may advance the development of clinical asthma (Balmes *et al*., 2003). Repeated and prolonged exposure to spray paint may cause permanent brain and nervous system damage sometimes referred to as painters' solvent syndrome (Dick *et al*., 2000). Although majority of the chemicals are non carcinogenic, repeated exposure especially to high concentration, may result in health impairment therefore resulted in increasing number of work days lost (Ho and Hite, 2008). Loss in produc- tivity means loss in revenue; therefore it is of utmost important for an employer to ensure that their workers are healthy.

In Malaysia, under the Occupational Safety and Health Act 1994, employers are responsible for protecting their workers from the adverse effect of chemicals. In this act, the assessment of chemicals used in the workplace must be performed in order to identify, evaluate and control health risk associated with exposure to chemicals. The regulatory agency in charge of providing the framework for managing chemical hazardous to health at the workplace is the Department of Occupational Safety and Health (DOSH), Ministry of Human Resources, Malaysia. Under the Occupational Safety and Health (Use and Standard of Exposure of Chemicals Hazardous to Health) Regulations 2000 (OSH-USECHH Regulations 2000), the duty to perform an assessment of health risks arising from the use of chemicals hazardous to health at the place of work is mandatory, whereby employers are not permitted to use any chemicals hazardous to health unless an assessment has been

conducted.

Under the USECHH Regulations 2000, a chemical hazardous to health is defined as any:

1. Chemical listed in the Schedule 1 to USECHH Regulations 2000
2. Chemicals categorized under Part B of the CPL Regulation 1997 (Classification, Packaging and Labeling Regulations 1997)
3. Pesticides (Pesticide Act 1974)
4. Scheduled waste listed in the First Schedule to the Environmental Quality (Scheduled Wasted) Regulations 1989

The objective of this study is to determine workers exposure to chemicals during installations and servicing of automobile air conditioner units. This study will assess the chemical risk and determine the adequacy of the existing control measure to control chemical exposure, following the OSH Regulations 2000 pro cedure. Exposure is evaluated using a qualitative exposure rating.

2. Materials and Methods

This study was conducted in a factory installing and servicing automotive air-conditioner unit. The premise is located in Selangor and has been in operation since 1979. This factory manufactured and traded in automotive air-conditioner units as OEM (Original Equipment Market) and REM (Replacement Equipment Market). There were 180 workers employed during the time of the study. Survey on work tasks and chemical exposure on workers were carried out upon receiving approval by the management. The evaluation of risk carried out was adapted from the Chemical Health Risk Assessment (CHRA) Manual (Department of Occupational Safety and Health (DOSH, 2000). This manual adopted a qualitative approach, where the severity of the hazard and the risk of exposure measured on a five rating scale (1-5, with increasing order of magnitude). Fig. 1 shows the flow chart of the evaluation of risk.

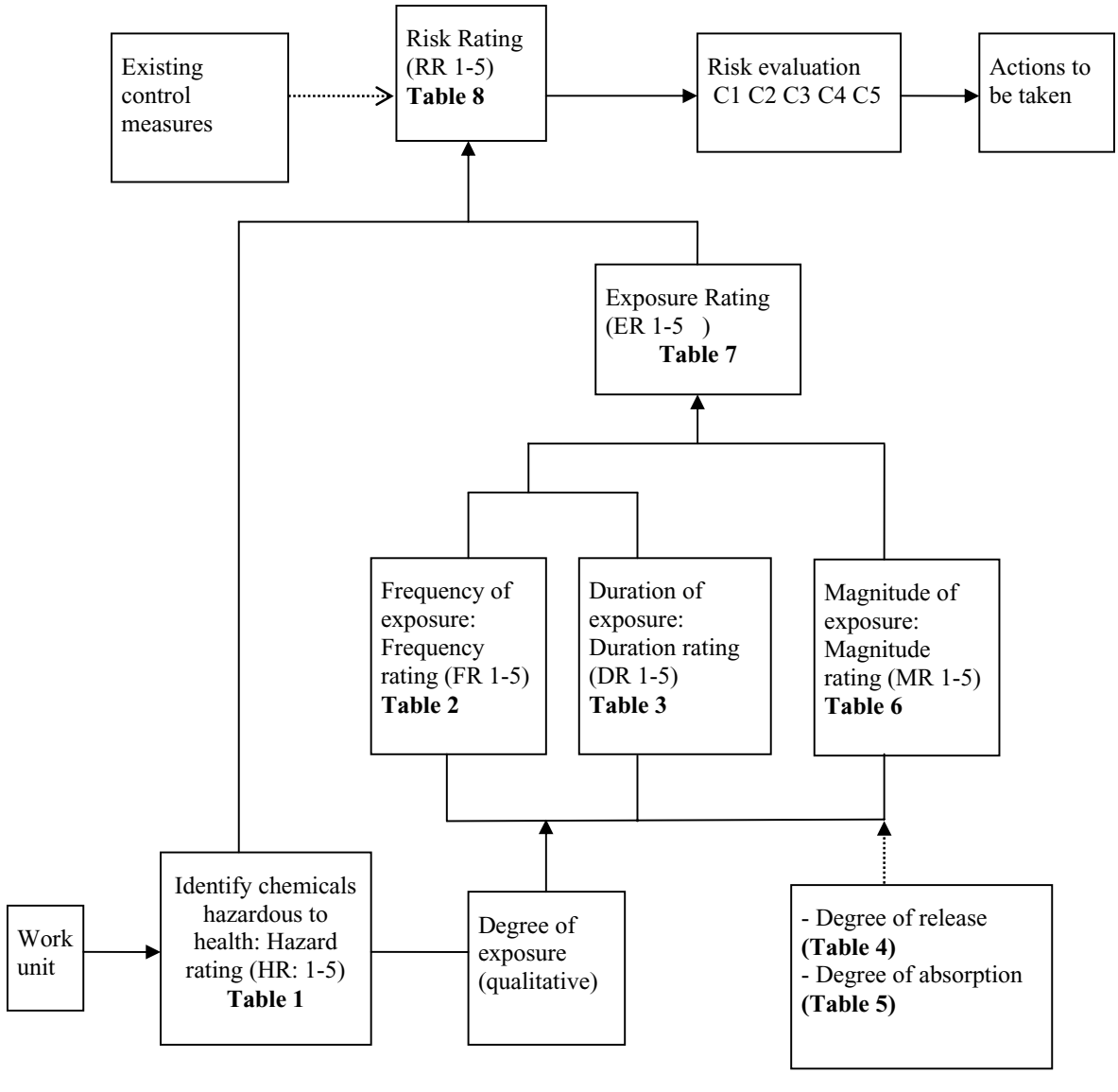

Figure 1. Flow chart for the evaluation of risk

Table 1. Assigned Hazard Rating (HR) (DOSH, 2000)

HR	HEALTH EFFECTS	HAZARD CATEGORY
5	Local: Injury to the skin, eyes, or mucous membranes of sufficient severity to threaten life by single exposure. Systemic: Severe irreversible effects (e.g. central nervous system effects, kidney necrosis, anemia or paralysis) after a single exposure.	Very toxic chemicals: LD50<25mg/kg (oral) LD50<50mg/kg (skin) LC50<0.5mg/litre
	Known human carcinogens, mutagens or teratogens.	Category 1 carcinogen, mutagen and teratogen.
4	Local: Injury to the skin, eyes, or mucous membranes of sufficient severity to cause permanent impairment, disfigurement or irreversible change from single or repeated exposure. Systemic: Very serious physical or health impairment by repeated or prolonged exposure.	Very corrosive (R35: Causes severe burn) Toxic chemicals: LD50: 25-200mg/kg (oral) LD50: 50-400mg/kg (skin) LC50: 0.5-2mg/litre
	Probable human carcinogens, mutagens or teratogens based on animal studies.	Category 2 carcinogen, mutagen and teratogen.
3	Local: Serious damage to skin, eyes or mucous membranes from single or repeated exposure. Systemic: Severe effects after repeated or prolonged exposure.	Corrosive (R34:Cause burn) Respiratory sensitisers Irritant-serious eye damage Harmful chemicals: LD50: 200-500mg/kg (oral) LD50: 400-2000mg/kg (sk) LC50: 2-20mg/litre
	Possible human or animal carcinogens or mutagens, but for which data is inadequate.	Category 3 carcinogen and mutagen.
2	Local: Reversible effects to the skin, eyes or mucous membranes not severe enough to cause serious health impairment. Systemic: Changes readily reversible once exposure ceases.	Skin sensitizers Skin irritants
1	No known adverse health effects.	Not classified as hazardous.

2.1. Exposure assessment

Initial exposure assessment was carried out by 'walk-through' inspection of each work unit with a check list of the following items: (i) engineering controls (such as isolation, enclosure); (ii) ventilation system (effective and adequately maintained); (iii) safe work practices; (iv) use and maintenance of proper personal protective equipments; (v) personal hygiene practices; (v) housekeeping practices; (v) hazardous substances storage; (v) waste disposal; and (v) emergency equipment and procedures.

Estimation of exposure assessment was based on the following parameters:

1) Categorization of work unit:
Workers exposed to the risk are grouped according to their work process. The work process of manufacturing air-conditioner parts can be divided into six sections:

1. Tube fin press section
2. Brazing section
3. Welding section
4. Final assembly section
5. Piping section
6. Kit II section

For each section, workers performed different tasks and used different chemicals.

2) Determination of the degree of hazard:
To determine chemicals hazardous to health, information is gathered from Material Safety Data Sheet (MSDS) and Chemical Safety Data Sheet (CSDS) records. These sources provide valuable information on hazard description, toxicity data, and health

Table 2. Frequency Rating (FR) (DOSH, 2000)

Rating	Description	Definition
5	Frequent	Potential exposure one or more time per shift or per day
4	Probable	Exposure greater than one time per week
3	Occasional	Exposure greater than one time per month
2	Remote	Exposure greater than one time per year
1	Improbable	Exposure less than one per year

effects. DOSH (2000) uses the Hazard Rating (HR) (Table 1) to describe the toxicity of the chemical based on the health effects and hazard categories.

3) Qualitative estimation of exposure:

a) Exposure parameters

The estimation for the degree of exposure is based on three parameters: (i) the frequency of exposure; (ii) duration of exposure and (iii) the qualitative estimation of magnitude of exposure.

i) Frequency of exposure

The Frequency Rating (FR) is based on observation of work practices as well as feedback from the workers and supervisors. The FR is shown in Table 2.

Table 3. Duration Rating (DR) (DOSH, 2000)

Rating	Total duration of exposure	
	% work hour	Duration per 8-hr shift or per 40-hr week
5	> 87.5 %	> 7 hrs/shift or > 35 hrs/week
4	> 50 - 87.5 %	4 - 7 hrs/shift or 20 - 35 hrs/week
3	25 - 50%	2 - 4 hrs/shift or 10 - 20 hrs/week
2	12.5 - 25 %	1 - 2 hrs/shift or 5 - 10 hrs/week
1	< 12.5%	< 1 hr/8-hr shift or < 5 hrs/week

Table 4. The degree of chemical release or presence for inhalation exposure (DOSH, 2000)

DEGREE	OBSERVATION
Low	- Low or little release into the air. - No contamination of air, clothing and work surfaces with chemicals capable of skin absorption or causing irritation or corrosion.
Moderate	- Moderate release such as: a) Solvents with medium drying time in uncovered containers or exposed to work environment. b) Detectable odour of chemicals with odour thresholds exceeding the PELs. - Evidence of contamination of air, clothing and work surfaces with chemicals capable of skin absorption or causing irritation orcorrosion.
High	- Substantial release such as a) Solvents with fast drying time in uncovered containers; b) Sprays or dust clouds in poorly ventilated areas; c) Chemicals with high rates of evaporation exposed towork environment; d) Strong odour of chemicals with odour thresholds exceeding the PELs. - Gross contamination of air, clothing and work surfaces with chemicals capable of skin absorption or causing irritation or corrosion.

Table 5. Degree of chemical absorbed or contacted (DOSH, 2000)

Degree	Observation/condition
Low	Low breathing rate (light work) Source far from breathing zone Contact with chemical other than those described under "Moderate" and "High". Small area of contact with chemicals capable of skin absorption - limited to palm (intact skin). <2% or 0.04m2 No indication of any skin conditions. Intact/normal skin No contamination of skin or eyes
Moderate	Moderate breathing rate (moderate work). Source close to breathing zone Contact with eye or skin irritants, sensitisers or chemicals capable of skin penetration, except those described under 'High' Moderate area of contact- one or both hands up to the elbows. Skin area >2% or 0.04m2 Skin dryness and detectable skin condition. Dry, red skin
High	High breathing rate (heavy work) Source within breathing zone Gross contamination of eye or skin with skin or eye irritants, sensitisers or chemicals capable of skin absorption Skin soaked or immersed in chemical capable of skin penetration Area of contact not only confined to hands but also other parts of body. Skin area>50% or 1m2 Follicle rich areas Skin damaged Severe drying, peeling and cracking

ii) Duration of exposure

The duration exposure is used to assess chronic or routine exposures where the calculated total exposure is the product of the number of exposures (as percent work hours) and the average duration for each exposure (based on 8-hr shift or 40-hr week) (as shown in Table 3).

iii) Magnitude of exposure.

The magnitude of exposure is based on the qualitative assessment of two parameters: (i) the degree of chemical released or presence based on the following characteristics: physicochemical properties, process characteristics, quantity used, method of handling, and the atmospheric conditions (Table 4) and (ii) the degree of chemical absorbed or contacted (Table 5). Information from the degree of chemical release or presence for inhalation exposure and the degree of chemical absorbed or contacted is incorporated into the Magnitude Rating (MR) table. The magnitude rating is shown in Table 6.

b) Exposure rating

An Exposure Rating (ER) is determined from the Frequency or Duration Rating and the Magnitude Rating (Table 7). If there have been confirmed cases of diseases occurrence associated with chemical exposure at the particular work unit, then the ER will be 5. Else, the assigned ER will be based on this matrix.

Table 6. Magnitude Rating (MR) (DOSH, 2000)

Degree of release	Degree of absorption	MR
Low	LowModerateHigh	123
Moderate	LowModerateHigh	234
High	LowModerateHigh	345

Table 7. Assigned Exposure Rating (ER) (DOSH, 2000)

		Magnitude Rating (MR)				
		1	***2***	***3***	***4***	***5***
Frequency	***1***	1	2	2	2	3
Rating/Duration	***2***	2	2	3	3	4
Rating	***3***	2	3	3	4	4
	4	2	3	4	4	5
	5	3	4	4	5	5

2.2. Risk Rating Matrix

Risk associated with chemical exposure is evaluated using a risk matrix. This matrix consists of values derived from ER and HR. A risk rating matrix is shown in Table 8. The purpose of this risk matrix is used to identify and prioritize actions to control risk. In implementing control measures, priorities must be given the degree of risk, the number of person at risk and the practicability of the control measures. A risk rating (RR) of 1 and 2 means that the risk of workers being exposed is low, indicating that the likelihood of exposure is low (ER=1) and the chemical is least hazardous (HR=1). In this situation, the risk is considered as 'not significant'. For these situations, the risk rating (RR) is either 1 or 2. When the chemical toxicity and exposure level are low (ER=2, HR=2), it is also considered as a 'non-significant risk'. A risk rating of 3 and 4 is considered as 'significant risk' where control actions must be implemented. A risk rating of 5 is considered as 'intolerable risk' where control action is of highest priority.

2.3 Risk evaluation for each work unit

After taking into account the risk ratings as well as the existence of control measures, the risk of exposure for each chemical is categorized into five levels (Refer to CHRA manual for further explanations):

- Risk not significant now and not likely to increase in future (C1)
- Risk significant but already adequately controlled, could increase in future (C2)
- Risk is significant now, and not adequately controlled (C3)
- Uncertain about risk; insufficient information (C4)
- Uncertain about risk; uncertain about degree and extent of exposure (C5)

Action strategies will be recommended based on each risk category in order to reduce exposure at work.

2.4. Health survey

Questionnaires were distributed among workers who are exposed to the chemicals. Interviews were conducted on all executives and officers in each section

Table 8. Risk Matrix (DOSH, 2000)

		EXPOSURE RATING (ER)				
		1	***2***	***3***	***4***	***5***
HAZARD RATING	***1***	RR=1	RR=2	RR=2	RR=2	RR=3
	2	RR=2	RR=2	RR=3	RR=3	RR=4
	3	RR=2	RR=3	RR=3	RR=4	RR=4
	4	RR=2	RR=3	RR=4	RR=4	**RR=5**
	5	RR=3	RR=4	RR=4	**RR=5**	**RR=5**

Note: RR = 1 and 2 risk not significant; RR = 3 and 4 risk significant; RR = 5 intolerable risk)

to gain complete and comprehensive information related to the actual work tasks. The respondents were selected from those who were exposed to chemicals in their work tasks. Seventy eight sets of questionnaires were distributed among six sections, i.e. Tube Fin Press (10), Brazing (40), Final Assembly (3), Welding (9), Kit 2 (5) and Piping (11). Another 15 questionnaires were distributed to those who were exposed to chemicals while doing inspection or repairing the machines: Production Engineering (5) and Quality Assurance (10).

2.5. Analysis of Data

All statistical analysis was performed using SPSS Windows (Statistical Package for Social Science). The multiple regression tests were performed to assess the significance of the health risks of chemicals exposed to the workers.

3. Results and Discussions

3.1. Worker's work profile

This study was carried out in a factory that manufactured and traded automotive air-conditioner units. There were 180 employees, 156 workers worked in the production line, which constitutes six section; tube fin pressed, brazing, welding, final assembly, piping and Kit II. Twenty four workers were not from the production line (quality assurance and production engineering department) who were involved in checking and inspection of products, and repairing and maintenance operations. Table 9 describes the number of workers involved in each department and who handled or were exposed to chemicals while at work. Based on their work assignment, 93 out of 180 (51.7%) of the workers were exposed to chemicals. The highest numbers of workers exposed to chemicals were from the brazing section (22.2%) while the final assembly was the lowest (1.7%). The workers worked from Monday to Friday. The day shift started at 8 am to 5 40 pm while the night shift were from 10 pm to 8 am the following day (Table 10). The total number of work hours per day was 8 hours and 45 minutes. The workers were assigned to their work section and seldom changed to different work sections.

Information obtained from the factory's material safety data sheet (MSDS) and chemical safety data sheet (CSDS) indicated that at least 22 types of chemicals were used in the production. Table 11 shows the list of chemicals used and its health effects. Most of the chemicals used were irritants (eye and skin) and some were asphyxiants and sensitizers. Sensitizers are chemicals that can induce occupational asthma.

3.2. Chemical risk assessment: qualitative approach

This study attempted to categorize chemical risk based on qualitative assessment of chemical exposure adapted from the Chemical Health Risk Assessment Manual, Department of Occupational Safety and Health (DOSH, 2000). Each compound used is assigned hazard rating (HR), duration rating (DR), magnitude rating (MR), and exposure rating (ER). The assigned ratings are shown in Table 12. Although the compound used in each work process involved mixtures of chemicals, only a single value is assigned. This value

Table 9. Number of workers employed by the factory

Section	Total numbers ofworkers	Numbers (%) of workers exposed to chemicals
Production line		
Tube Fin Pressed	27	10 (5.6)
Brazing	42	40 (22.2)
Welding	22	9 (5.0)
Final Assembly	20	3 (1.7)
Piping	26	11 (6.1)
Kit II	20	5 (2.8)
Other departments:		
Quality Assurance	12	10 (5.6)
Production Engineering	12	5 (2.8)
Total	180	93 (51.7)

Table 10. Work time activity patterns in the production works

Time (hour)	Work activities	Duration (minute)
0800-0810	Briefing	10
0810-0930	Working in each section	80
0930-0945	Tea-break	15
0945-1200	Working in each section	135
1200-1245	Lunch	45
1245-0300	Working in each section	135
0300-0315	Tea-break	15
0315-0530	Working in each section	135
0530-0540	Cleaning up	10
After 0540	End of the work	-

Table 11. List of chemicals used at the facility and their health effects compiled from material safety data sheet (MSDS) and chemical safety data sheet (CSDS).

Chemical (Trade Name)	Chemical component	Health effects
Arox Finpunch EH-10	-Synthetic hydrocarbon and special additive ester	- Slight irritation on the skin and eyes, not a sensitizer. - Repeated or long contact can lead to leaving skin fats or to dermatitis, through this the skin can become sensitive to other materials or chemicals.
Amoil FP-20	-Odorless synthetic hydrocarbon	- Slight irritation on the skin and eyes, not a sensitizer. - Repeated or long contact can lead to leaving skin fats or to dermatitis, through this the skin can become sensitive to other materials or chemicals.
Betz Kleen 180	-Potassium hydroxide -Sodium tripolyphosphate -Benzenemethanaminium (N,N-dimethyl-N-octyl chloride)	- Corrosive: Harmful by ingestion, inhalation and in contact with skin. - Eye and skin irritant, toxic to lungs
FL-7	-Potassium cryolite	- Possible irritation to mucus membrane, eyes, skin. - Risk of respiratory sensitization - Chronic exposure can induce bone calcification disorder
Nocolok ® 100 Flux	-Aluminium potassium fluoride	- Irritating to eyes - Risk of respiratory sensitization - chronic exposure can cause dental and bone fluorosis
Argon, Refrigerated Liquid LPGas	-Argon	- asphyxia if released in a confined area, - Skin or exposed tissue frosbite - Concentration in air > 10% causes immediate dizziness - Asphyxia in high concentration. - Skin frostbite

Chemical (Trade Name)	Chemical component	Health effects
Oxygen	-Oxygen	- Hyperoxia which leads to pneumonia
Helium, Gas	-Helium	- Asphyxia in high concentration - sources of helium may contain small amounts of arsenic compounds
Nitrogen, Refrigerated Liquid	-Nitrogen	- asphyxiation if released in a confined area, - frostbite or freeze burns in exposed tissues.
Omni LTB 718 FCW	-AluminiumSilicon	- Eye and skin irritant - Vapors may cause central nervous system depression (drowsy, loss of coordination) - Alloy and flux may cause slight skin irritation - Vapors may cause eye irritation
Superlac A6004-2136 Fujiyama Black	-Acrylic resin, alcohol, aromatic hydrocarbon, bisphenol A-epichloroydrin, carbon black, hydrocarbon, melamine resin in butanol, metal carboxylate and others	- Eye and skin irritant - Harmful by inhalation and swallowed - Repeated and prolonged exposure to solvent with permanent brain and nervous system damage (sometimes referred to as painters' solvent syndrome).
Superlac 6004-060 ES Thinner	-Alcohol, ester, ethers and hydrocarbon	- Eye and skin irritant - Harmful by inhalation and swallowed - Risk of serious damage to eyes. - Repeated and prolonged occupational to solvent with permanent brain and nervous system damage
Parco spray booth compound 2378	-Sodium hydroxide, sodium metasilidate	- Contact with eyes will cause severe burns and possible blindness, severe burns on skin and possible ulceration. - Gastrointestinal damages and burns of the digestive tract. - Inhalation of dust can cause injury (burns) to the entire respiratory tract.
P3 ® Peelable Masking 2498	-Acrylic powder, vinyl acrylic latex	- Eye and skin irritant - Prolonged or repeated contact may cause irritation on skin, mouth and throat, nausea and vomiting. - Inhalation of vapor or mist can cause irritation of the nose, throat, and lungs; also may cause headache and nausea.
Al-Flux 2805	-Potassiumfluoro-aluminate	- Eye, skin, respiratory tract and mucous membrane irritant - Repeated and longer lasting exposition there's a risk of sore throat, nosebleed and chronic bronchitis.

Chemical (Trade Name)	Chemical component	Health effects
Instapak ® Port Cleaner	-Diisobutyl DBE	- A single exposure by inhalation caused body weight loss and clear ocular discharge during exposure. Post-exposure corneal cloudiness and slight to severe body weight loss occurred. - Mild skin and eye irritant. - Single doses by ingestion caused weakness, moderate weight loss and nonspecific effects.
Metal Quest 201A	-Sulfur type extreme pressure additive, chlorine type extreme pressure additive, oiliness improper, special additives (for anti-oxidization) and petroleum hydrocarbon	- Slightly irritating but does not injure eye tissue. - Frequent or prolonged contact may irritate and cause dermatitis. - Ingestion may cause irritation of digestive tract and diarrhea. Small amounts of this product aspirated into the respiratory system during ingestion or vomiting may cause mild to severe pulmonary injury.
IMEC 514 Industrial Degreaser	-Alkaline silicate, phosphate mixture.	- Eye and skin irritant - May cause nausea, dizziness, headache and transient reddening of skin.
Kleenetch (Aluetch)	-Hyrofluoric acid, sulphuric acid	- Corrosive and severe irritants will cause eye tissue damage, severe burns on skin and severe gastric burning through ingestion. - Inhalation of vapor / mists will cause severe inflammation.
Durospray	-Synthetic rubber adhesive	- Prolonged repeated contact may defeat skin and lead to skin dryness and / or irritation leads to dermatitis. - High vapor concentrations are irritating to the eyes and respiratory tract. - May cause headaches and dizziness. - On contact, will glue eyelids together and injure eye tissues.
Forane ® 134a	-1,1,1,2-Tetrafluoroethane	- Frostbite on skin and eyes - asphyxiation if excessively inhaled

is based on the greatest HR obtained from individual chemical contained in the mixture. For further explanation, refer to the CHRA Manual. The HR for each compound ranged from 1 (oxygen) to 4 (thinners, cleaning acids, and rubber adhesives). Fourteen of the 26 chemicals (53.8%) were rated as 3. The ER for each compound ranged from 2 to 4 where 34.6% (9/26) of the chemicals used were rated as 3 and 46.2% (12/26) rated as 4.

The chemicals were then assigned RR, indicating the likelihood of illness. RR is estimated from the assigned HR and ER. RR is used to identify areas that need control strategies to minimize exposure to chemicals. Risk is evaluated as either "significant" or "not significant". Table 13 shows the assigned risk matrix for each work unit. The works sections where risk is significant were final assembly (RR 3 and 4), piping (RR 3 and 4), Kit II (RR Control action is needed but of lower priority compared to chemicals assigned with RR 5. No chemicals were rated as RR 5.

Table 12. Assigned Hazard Rating (HR), Duration Rating (DR), Magnitude Rating (MR), and Exposure Rating(ER).

Work unit	Work Process	Chemical	Chem. content	HR	DR	MR	ER
Tube Fin Press	CPA-2: Cleaning-Degreaser	IMEC 514 Industrial Degreaser	Alkaline Silicate andPhosphate Mixture.	3	3	4	4
	SPA-1: Punch	Arox Finpunch EH-10	Synthetic Hydrocarbon and special additive Ester.	2	4	2	3
		Amoil FP-20	Odorless synthetic hydrocarbon	2	4	2	3
Brazing	CBB-1: Degreasing	Betz Kleen 180	Potassium hydroxide, Sodium tripolyphosphate and Benzenemethanaminium, N,N-dimethyl-N-octyl chloride	3	4	3	4
	CBB-2: Add flux	FL-7	Potassium Cryolite	2	4	3	4
		Nocolok 100 Flux	Aluminium potassium fluoride	2	4	3	4
	CBB-3: Nocolok brazing	Al-Flux 2805	Potassiumfluoroaluminate	3	4	3	4
Welding	WSC-2: T.I.G Welding	Argon	Argon	2	4	1	2
	WSC-3: Auto braze	LPGas	Anhydrous ammonia, propane, butane	2	4	1	2
		Oxygen	Oxygen	1	4	1	2
	WSC-4: Manual braze	Omni LTB 718 FCW	Aluminium and Silicon	3	4	3	4
	WSC-6: Helium leak test	Helium	Helium	3	1	2	2
	WSC-11: Water bath leak test (nitrogen)	Nitrogen	Nitrogen	3	4	4	4
Final Assembly	CAD-3: Painting	Superlac A6004-2136 Fujiyama Black	Acrylic Resin, Alcohol, Aromatic Hydrocarbon, Bisphenol A-epichloroydrin, Carbon black, Hydrocarbon, Melamine Resin in Butanol, Metal Carboxylate and others.	3	3	4	4
	CAD-3: Painting	Superlac 6004-060 ES Thinner	Alcohol, ester, ethers and hydrocarbon.	4	3	4	3

Work unit	Work Process	Chemical	Chem. content	HR	DR	MR	ER
		Parco spray booth	Sodium hydroxide and Sodium metasilidate	3	3	3	3
		P3 Peelable masking 2498	Acrylic powder and vinyl acrylic latex	3	3	3	3
	CAD-13: Charge gas	Nitrogen	Nitrogen	3	2	3	3
	CAD-15: Insert instapak	Instapak Port Cleaner	Diisobutyl DBE	3	2	3	3
Piping	WPF-6: Drilling	Metal Quest 201A	Sulfur type extreme pressure additive, Chlorine type extreme pressure additives, oiliness improper, special additives (for anti-oxidization) and petroleum hydrocarbon.	2	3	2	3
	WPF-10: Flux brazing	Omni LTB 718 FCW	Aluminium and Silicon	3	4	3	4
		Al-4310 Powder	Aluminium	3	4	3	4
	WPF-11: Cleaning (Acid)	IMEC 514 Industrial Degreaser	Alkaline Silicate and Phosphate Mixture.	3	2	4	3
	WPF-11: Cleaning (Acid)	Kleenetch (Aluetch)	Hyrofluoric acid and Sulphuric acid	4	2	4	4
Kit II	EUE-9: Install casing	Durospray	Synthetic rubber adhesive	4	2	4	4
	EUE-14: Charge gas	Forane 134a	1,1,1,2-Tetrafluoroethane	2	2	2	2

3.3. Workers health status

We attempted to establish the relationship between the assigned RR for each compound with the reported symptoms obtained from the distributed questionnaires.

a) Tube Fin Press section: the reported occurrence of skin dryness, skin irritation and redness, and respiratory irritation was significantly related ($p = 0.01$) with the use of IMEC 514 Industrial degreaser (RR = 4).
b) Brazing Section: the reported occurrence of eye irritation ($p = 0.001$) and skin irritation ($p = 0.001$) with the use of FL-7 and Nocolok 100 Flux (RR = 3) was significant. The workers were observed using rubber gloves while adding flux, but they did not protect their face (using dust mask, safety goggles or chemical proof goggles). However, no significant relationship was established between adverse symptoms with the use of Betz Kleen and Al-Flux 2805 although the assigned risk RR = 4. For this job task, they were observed wearing proper PPE.
c) Welding Section: the use of argon (RR = 2) and Omni LTB 718 FCW (RR = 4) was associated with respiratory infection ($p=0.01$); oxygen (RR = 2), LPGas (RR = 2) and helium (RR=3) associated with severe burn of tissues

(*p=0.01*); and nitrogen (RR = 4) with eye irritation and severe burn of tissues (*p=0.01*). The worker was observed not using the face shield and goggles in the auto braze process, and safety glasses, protective gloves and mask (3M) in the manual braze process. Workers did not wear cotton gloves, long sleeves shirt and full-face mask while conducting the Helium leak test.

d) Final Assembly Section: the RR values of all chemicals used ranged from 3-4. These chemicals were used together in the painting process and the combined effects caused coughing, eye and skin irritation (*p=0.01*).
e) Piping Section: occurrence of respiratory irritation is associated with the use of Metal Quest 201A (RR = 3) (*p=0.01*); Al-Flux 2805 and Omni LTB 718 FCW associated with skin irritation (*p=0.01*); and IMEC 514 (RR = 3) Industrial Degreaser and Kleenetch (RR = 4) associated with respiratory irritations (*p=0.01*). Workers were observed wearing safety glasses, protective gloves, safety shoes (except Mask 3M) and long sleeves shirt.
f) Kit II Section: occurrence of eye irritation is significantly related with the use of Durospray (RR = 4) (*p=0.01*). Workers were observed using face shield, cotton gloves, mask, apron and cartridge except rubber gloves, safety glasses and long-sleeved coveralls.

Based on this cross-sectional study, we found that workers reported experiencing adverse symptoms related to exposure to chemicals at work.

Table 13. Risk matrix for all work units

		EXPOSURE RATING				
WORK UNIT		***1***	***2***	***3***	***4***	***5***
FINAL ASSEMBLY	***1***					
	2					
	3			**RR=3** Parco spray booth compound, 2378 P3 Peelable Masking 2498, Nitrogen, Instapak Port Cleaner	**RR = 4** Superlac A6004-2136, Fujiyama Black	
	HAZARD RATING					
	4				**RR = 4** Superlac 6004-060 ES Thinner	
	5					
PIPING	***1***					
	2			**RR = 3** Metal Quest 201A		
	3			**RR = 3** IMEC 514 Industrial Degreaser	**RR = 4** Omni LTB 718FCW Al-4310 Powder	
	4			**RR = 4** Kleenetch		
	5					

Table 13. Risk matrix for all work units

		EXPOSURE RATING				
WORK UNIT		*1*	*2*	*3*	*4*	*5*
KIT II		*1*				
		2	**RR = 2** Forane 134a			
		3				
		4		**RR = 4** Durospray		
		5				
TUBE FIN PRESS		*1*				
		2		**RR*= 3** Arox Finpunch EH-10, Amoil FP-20		
		3			**RR = 4** IMEC 514 Industrial Degreaser	
	HAZARD RATING					
		4				
		5				
BRAZING		*1*				
		2			**RR = 3** FL-7,Nocolok 100Flux	
		3			**RR = 4** Betz Kleen 180 Al-Flux 2805	
		4				
		5				
WELDING		*1*	**RR = 2** Oxygen			
		2	**RR = 2** Argon LPGas			
		3	**RR = 3** Helium		**RR = 4** Omni LTB 718 PCW	
		4				
		5			Nitrogen	

3.4. Chemical risk evaluation at work unit

Taking into consideration risk decisions (assigned RR values) and the adequacy of existing control measures, several findings could be reached (as shown Table 14).

1) The work area that is categorized as C1 (where risk not significant now and not likely to increase in the future) include: the Welding section (for Oxygen, Argon ,and LPGas, and the Kit ll section (for Forane 134a). For these areas, the chemicals can be readily controlled in accordance with CSDS and there is no significant health risk. For this area, the recommended action to be taken is to conduct chemical review assessment every five years or as directed by DOSH.
2) The work area categorized as C2 (where the risk is significant but already adequately controlled but could increase in the future)

include: the Tube Fin Press Section (for Amoil FP-20 and Arox Finpunch EH-10); the Brazing Section (for FL-7 and Nocolok 100 Flux); the Welding Section (for Helium); the Final Assembly Section (for Parco spray booth compound 2378, P3 Peelable Masking 2478, Nitrogen and Instapak Port Cleaner); and the Piping Section (for Metal Quest 201A and IMEC 154 Industrial Degreaser). For these areas, the adverse health effects could increase in the future, if control measures fail or deteriorate. Recommended actions to be taken include: determine additional precautions and measures to prevent chances of higher exposure and accidental release; and health surveillance on workers to determine the effectiveness of the controls.

3) The work area categorized as C3 (where risks are significant now, and not adequately controlled) include: the Tube Fin Press Section (for IMEC 514 Industrial Degreaser); the Brazing Section (for Betz Kleen 180 and Al-Flux 2805) ; the Welding Section (for Omni LTB 718FCW and Nitrogen); the Final Assembly Section (for Superlac A6004-2136 Fujiyama Black and Superlac 6004-060 ES

Table 14. Chemical risk evaluation for each work unit

Work unit	Chemicals	Risk evaluation				
		C1	C2	C3	C4	C5
Tube Fin Press	1. Arox Finpunch EH-10		X			
	2. Amoil FP-20		X			
	3. IMEC 514 Industrial Degreaser			X		
Brazing	1. FL-7		X			
	2. Nocolok 100 Flux		X			
	3. Betz Kleen 180			X		
	4. Al-Flux 2805			X		
Welding	1. Oxygen	X				
	2. Argon	X				
	3. LPGas	X				
	4. Helium		X			
	5. Omni LTB 718FCW			X		
	6. Nitrogen			X		
Final assembly	1. Parco spray booth compound 2378		X			
	2. P3 Peelable Masking 2498		X			
	3. Nitrogen		X			
	4. Instapak Port Cleaner		X			
	5. Superlac A6004-2136 Fujiyama Black			X		
	6. Superlac 6004-060 ES Thinner			X		
Piping	1. Metal Quest 201A		X			
	2. IMEC 514 Industrial Degreaser		X			
	3. Kleenetch			X		
	4. Omni LTB 718FCW			X		
	5. Al-4310 Powder			X		
Kitt II	1. Forane 134a		X			
	2. Durospray			X		

Risk not significant now and not likely to increase in future (C1)
Risk significant but already adequately controlled, could increase in future (C2)
Risk is significant now, and not adequately controlled (C3)
Uncertain about risk; insufficient information (C4)
Uncertain about risk; uncertain about degree and extent of exposure (C5)

Thinner); the Piping Section (for Omni LTB 718FCW, Al-4310 Powder and Kleenetch), and the Kit II Section (for Durospray). For these areas, the workers are at risk of adverse health effects since chemical exposure is not adequately controlled. The following were observations made :

(i) Brazing Section: The workers transferred Al-Flux 2805 (liquid form) into a holding tank manually by lifting the container and poured the Flux into the holding tank. This handling technique increases the risk of spillage. The safer alternative would be to use an electrical hand pump to transfer the liquid.

(ii) Piping Section: an isolated compartment or enclosed area should be installed where Kleenetch is used. The compartment should also be equipped with a capture hood. Currently, the workers were exposed to strong odors from the acid degreaser cleaning process.

(iii) Final Assembly Section: Workers complained of feeling hot. No ventilation system was installed to extract the heat produced during the manual or auto brazing process.

Recommended actions to be taken include: implement immediate measures for preventing or controlling exposure; prevent accidental release; health surveillance on workers to determine the effectiveness of the controls; and determine the need for retraining of employees.

4. Conclusion

Using a qualitative exposure assessment, this study has identified that all the six work units have several work processes that is likely to increase the risk of workerûs exposure to chemicals. The work process that is categorized as "the risk is significant but already adequately controlled but could increase in the future)" were: Tube Fin Press Section (for Amoil FP-20 and Arox Finpunch EH-10); the Brazing Section (for FL-7 and Nocolok 100 Flux); the Welding Section (for Helium); the Final Assembly Section (for Parco spray booth compound 2378, P3 Peelable Masking 2478, Nitrogen and Instapak Port Cleaner); and the Piping Section (for Metal Quest 201A and IMEC 154 Industrial Degreaser). For these areas, the adverse health effects could increase in the future, if control measures fail or deteriorate. Recommended actions to be taken include: determining additional precautions and measures to prevent chances of higher exposure and accidental release; and health surveillance on workers to determine the effectiveness of the controls.

The work process that is categorized as "the risk is significant and not adequately controlled" were: the Tube Fin Press Section (for IMEC 514 Industrial Degreaser); the Brazing Section (for Betz Kleen 180 and Al-Flux 2805); the Welding Section (for Omni LTB 718FCW and Nitrogen); the Final Assembly Section (for Superlac A6004-2136 Fujiyama Black and Superlac 6004-060 ES Thinner); the Piping Section (for Omni LTB 718FCW, Al-4310 Powder and Kleenetch), and the Kit II Section (for Durospray). For these areas, the workers are at risk of adverse health effects since chemical exposure is not adequately controlled.

Based on this cross-sectional study, we found that workers reported experiencing symptoms such eye irritation, severe burn of tissues, skin dryness, skin irritation and redness, and respiratory irritation. One worker suffered a miscarriage but we were not able to show it was due to chemical exposure.

This risk ranking method provides a valuable insight for the development risk prioritization in work areas to minimize chemical exposure. This approach is suitable for small to medium industries (SMI) that cannot afford to carry out quantitative analysis and to ensure that any resources allocated for risk reduction are optimized.

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