# RESPIRABLE DUST EXPOSURE ($PM_{2.5}$) AND RESPIRATORY HEALTH AMONG MALE QUARRY WORKERS, KELANTAN

by

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ACGIH | American Conference of Governmental Industrial Hygienists |
| *Adj* OR | Adjusted Odds Ratio |
| ATS | American Thoracic Society |
| BMRC | British Medical Research Council |
| CEN | European Standards Organization |
| CI | Confidence Interval |
| $CO_2$ | carbon dioxide |
| COPD | chronic obstructive pulmonary disease |
| COSHH | Control of Substances Hazardous to Health |
| df | Degree of Freedom |
| DOSH | Department of Occupational Safety and Health |
| *et al.* | *et alia* (and others) |
| $FEV_1$ | Forced Expiratory Volume in one second |
| $FEV_1/FVC$ | Forced Expiratory Volume in one second per Forced Vital Capacity |
| FVC | Forced Vital Capacity |
| Hb | haemoglobin |
| $HBO_2$ | oxyhaemoglobin |
| ISO | International Organization for Standardization |
| LTF | Lung Function Test |
| MLR | Multiple Linear Regression |
| NIOSH | National Institute for Occupational Safety and Health |
| $O_2$ | oxygen |
| OR | Odds Ratio |
| OSHA | Occupational Safety and Health Administration |
| PEF | Peak Expiratory Flow |
| PEL | Permissible Exposure Limit |
| PFT | Pulmonary function tests |
| $PM_{2.5}$ | Particulate Matter 2.5 micron |
| $pO_2$ | partial pressure of oxygen |

| | |
|---|---|
| PPE | Personal Protective Equipment |
| RCS | Respirable crystalline silica |
| ROS | reactive oxygen species |
| SD | Standard Deviation |
| $SiO_2$ | silicon dioxide |
| -SiOH | silanol groups |
| SLR | Simple Linear Regression |
| STEL | short term exposure limit |
| TWA | 8-hour time-weighted average |
| VC | vital capacity |
| vs | versus |
| WEL | Workplace Exposure Limits |
| WHO | World Health Organisation |
| % | Percentage |
| ≥ | more than or equal to |
| $\chi^2$ | Pearson Chi-Square |
| < | less than |
| > | more than |
| *b* | beta |
| cm | centimetre |
| m | meter |
| $mg/m^3$ | milligram per cubic meter |
| n | number |
| N | total number |
| μm | micrometre |

**PENDEDAHAN HABUK TERNAFAS ($PM_{2.5}$) AND KESIHATAN PERNAFASAN DALAM KALANGAN PEKERJA LELAKI KUARI, KELANTAN**


## ABSTRAK

Pendedahan habuk di tempat kerja merupakan masalah biasa yang dikaitkan dengan penyakit pernafasan dan telah dikaji sejak berdekad lamanya. Satu kajian keratan rentas telah dijalankan untuk menentukan perhubungan antara pendedahan habuk ternafas ($PM_{2.5}$) dengan kesihatan pernafasan dalam kalangan pekerja kuari. Kajian ini telah dijalankan terhadap 50 orang pekerja lelaki kuari dan 50 orang pekerja lelaki pentadbiran. Responden ditemuramah menggunakan soal selidik "British Medical Research Council" (BMRC) mengenai gejala pernafasan dan fungsi paru-paru diukur dengan menggunakan spirometer. Persampelan habuk peribadi telah diukur dalam kalangan pekerja kuari menggunakan TSI SidePak™ AM510. Purata bagi pendedahan habuk ternafas adalah lebih tinggi di bahagian "grinding bunker" (0.26±0.26 $mg/m^3$). Penemuan kajian ini melebihi Had Pendedahan yang Dibenarkan (PEL) (0.10$mg/m^3$) untuk Purata Wajaran Masa 8 jam (TWA 8j) berdasarkan US Occupational Safety and Health Administrative (OSHA) dan Peraturan Kawalan Keselamatan dan Peraturan Keselamatan Bahan Kimia Berbahaya (COSHH) 2002. Gejala pernafasan yang dilaporkan dalam kalangan pekerja lelaki kuari adalah kahak (46.0%, n=50), kesukaran bernafas (36.0%, n=50), batuk (32.0%, n=50) dan sesak dada (22.0%, n=50). Umur mempunyai perhubungan yang bererti dengan kesukaran bernafas (*Adj* OR: 1.564, SK 95%: 1.049, 2.333) Terdapat perbezaan bererti terhadap %$FEV_1$/FVC antara pekerja kuari dengan kumpulan kawalan ($p<0.001$, $t=-3.729$). Merokok menunjukan perhubungan yang bererti dengan FVC ($b=-0.412$, $p<0.05$) manakala umur menunjukkan perhubungan yang bererti dengan $FEV_1$ ($b=-0.026$, $p<0.05$) dan %FEV1/FVC ($b=-0.416$, $p<0.05$). Kesimpulannya, kajian mendapati bahawa tiada perhubungan antara pendedahan habuk ternafas ($PM_{2.5}$) terhadap kesihatan pernafasan pekerja kuari. Walaubagaimanapun, penambahbaikan terhadap kawalan kejuruteraan dan pengubahsuaian amalan kerja perlu dilakukan untuk mengurangkan pendedahan terhadap habuk ternafas ke tahap yang selamat.

# RESPIRABLE DUST EXPOSURE ($PM_{2.5}$) AND RESPIRATORY HEALTH AMONG MALE QUARRY WORKERS, KELANTAN

## ABSTRACT

Exposure to workplace dust is a common problem associated with respiratory illnesses and has been an area of research interest for the last decades. A cross sectional study was carried out to determine the association of respirable dust exposure ($PM_{2.5}$) and respiratory health among male quarry workers. This study was conducted among 50 male quarry workers and 50 male administrative workers. The investigation included spirometric testing and detailed personal interviews using structured questionnaire adopted from British Medical Research Council (BMRC) Questionnaire on respiratory symptom. Personal exposure of respirable dust was measured among the quarry workers by using TSI SidePak™ AM510. The mean personal monitoring of respirable dust among exposed group was higher at grinding bunker section (0.26±0.26 mg/m$^3$). This result exceeding permissible exposure limits (PEL) (0.10mg/m$^3$) 8 hours Time Weighted Average (TWA-8h) according to US Occupational Safety and Health Administrative (OSHA) and Control of Substances Hazardous to Health Regulations 2002. Respiratory symptoms reported by male quarry workers were phlegm (46.0%, n=50), dyspnea (36.0%, n=50), cough (32.0%, n=50) and chest tightness (22.0%, n=50). Age had significant relationship with the dyspnea (*Adj* OR: 1.564, CI 95%: 1.049, 2.333). There was a significant different of %$FEV_1$/FVC between quarry workers and control group. Smoking was significantly associated with FVC ($b$=-0.412, $p<0.05$) while age was significantly associated with $FEV_1$ ($b$=-0.026, $p<0.05$) and %FEV1/FVC ($b$=-0.416, $p<0.05$). In conclusion, there was no association between respirable dust exposure ($PM_{2.5}$) and respiratory health among the quarry workers. However, improvement on engineering control and work practices modifications should be done to reduce exposure of respirable dust to safe personal exposure.

# CHAPTER 1

# INTRODUCTION

## 1.1 Study Background

Mining and Quarrying Safety and Health Act 1999 (2014) stated that quarry is a place on land where operations are carried on, continuously or from time to time, to produce construction or road building material. The quarry and mining industry plays an important role in the development of the country. The industry guarantees adequate and continues supply of raw materials to the construction, building and manufacturing sectors for the economic development of the country (Norhidayah *et al.*, 2014). Even though mining and quarry are not a higher ranking sector, however they also contribute to the industrial accidents and listed as one of the most hazardous occupations (Nur Azlina *et al.*, 2013). In India, particularly in Nellore, quarrying products are increasingly in demand for industrial growth, domestic, agricultural and other purpose (Kiran Kumar *et al.*, 2014). Quarrying could be done in diverse methods such as hard rock mining, using rock drills, explosion of dynamite and other sophisticated methods (Ukpong, 2012). This quarrying activity causes negative impact such as land degradation, swamp creation, deterioration of ground water, erosion of soil, noise and percussions from rock blasting, generation of dust, smoke and fumes, production of noxious gases and ground vibration (Ugbogu *et al.*, 2009). The health impacts of working in quarrying industry have been well documented (Nwibo *et al.*, 2012). Many researches have investigated the effect of occupational dust concerning the relationship between dust exposure and respiratory health among quarry workers locally and aboard, but still lacking the appropriate assessment of dust exposure to the workers.

Nwibo *et al.* (2012) stated that dust exposure is one of the major health hazards to respiratory health. Dusts can be classified as either total inhalable dust or respirable dust. Dust may cause potential risks to human health (workers and surrounding populations), to environment, working conditions and workers' productivity. Its effects depend on particles concentration, size, shape, sharp edges and their chemical composition (Petavratzi *et al.*, 2005). The categories are different and related to size of the dust particles in the atmosphere. The respirable dust being finer and able to penetrate further into the lungs where it remains. A major health risk encountered by people working in the quarrying industry is exposure to fine respirable dust which contains silica. Silica is found in majority of rocks, sands and clays. Therefore workers within the quarrying industry and masonry industry are particularly susceptible (Health and Safety Authority, 2015).

Occupational respiratory disease is identified as the accumulation of the conditions of the respiratory system which are the risk factors to the particular disease (Naemah *et al.*, 2015). Respiratory system or ventilator system is a biological system consists of specific organ and structure to ensure the oxygen is brought into the body, made available to each cell needed and also ensuring carbon dioxide leaves the cell and remove from the body (Gardner *et al.*, 2000). The continuous respirable dust exposure to the workers may give adverse affect to respiratory functions.

### 1.2 Problem Statement

Whenever people inhale airborne dust at work, they are at risk of occupational disease. Year after year, both in developed and in developing countries, overexposure to dusts cause diseases, temporary and permanent disabilities and deaths (WHO, 1999). The nature of working environment in quarries produces the dust emission which is the most critical hazards. The effects of dust exposure on the health of workers can be worsen if employees and management do not apply the work safety practices and do not comply with the use of personal protective equipment (PPE). Furthermore, lack of knowledge and awareness should be improved in order to overcome the occupational disease. Improper occupational hygiene practice in workplace will effect both of worker wellbeing and productivity (Nurul *et al.*, 2014)

People working in the quarrying industry encounter health risk which contain silica in the respirable dust. Silica is allergenic and irritates to the respiratory tract which lead to unproductive cough and other respiratory symptoms. Precautionary measures against inhalation dust at the rock crushing sites are generally poor or non-existent owing to lack of resources by management and ignorance of the rock crashers (Urom *et al.*, 2005). The occupational dust also impairs the lung function and cause pneumoconiosis.

The major respiratory symptoms among quarry workers include non-productive cough, chest pain, catarrh and dyspnea (Urom *et al.*, 2005). In Malaysia, there were several studies conducted on respiratory symptoms and dust exposure among working population in dusty environment (Razlan *et al,* 2002, Nurul *et al,* 2014). These studies revealed the association between occupational exposure to dust and respiratory impairment. However, local researchers only identified the prevalence of respiratory symptoms and lung function among quarry workers without measuring the amount of dust exposure (personal or work environment) (Razlan *et al.*, 2002). Therefore, the association of dust exposure and respiratory health is unclear. In addition, no local studies reported the association between frequency of use of personal protective equipment (PPE) (mask) and respiratory health among quarry workers.

Previous studies found that the Forced Vital Capacity (FVC), Forced Expiratory Volume in one sec ($FEV_1$) and $FEV_1/FVC$ ratio were significantly reduced among the quarry workers (Razlan *et al.*, 2002; Urom *et al.*, 2005). Their findings indicated the quarry workers had restrictive lung function impairment (Razlan *et al.*, 2002; Urom *et al.*, 2005; Kiran Kumar *et al.*, 2014). The duration of exposure is one of the major predisposing factors in the aetiology of lung function impairment among the granite-dust workers (Urom *et al.*, 2005).

## 1.3 Objectives

### 1.3.1 General objective

To investigate the relationship between the concentration of respirable dust exposures ($PM_{2.5}$) and respiratory health among male quarry workers.

### 1.3.2 Specific objectives

- To measure the concentration of respirable dust exposure ($PM_{2.5}$) among the quarry workers.
- To determine and compare the prevalence of respiratory symptoms (cough, phlegm, chest tightness & dyspnea) among exposed group (quarry workers) and control group.
- To measure and compare the lung function (FVC, $FEV_1$ and $\%FEV_1/FVC$) among exposed group (quarry workers) and control group.
- To determine the association of reported respiratory symptoms with associated factors (socio-demographic, concentration of respirable dust exposure ($PM_{2.5}$), safety practices)
- To determine the association of lung function with associated factors (socio-demographic, concentration of respirable dust exposure ($PM_{2.5}$), safety practices)

## 1.4 Research Hypothesis

- There is significant difference of respiratory symptoms (cough, phlegm, chest tightness & dyspnea) between exposed and control group.
- There is significant difference of lung function ($FEV_1$, FVC, %FEV1/FVC) between exposed and control group.

- There is significant association between respiratory symptoms with demographic factors (age, smoking), occupational exposure (respirable dust exposure and duration of work) and safety practice (using mask).
- There is a significant association between lung function with demographic factors (age, smoking), occupational factors (respirable dust exposure and duration of work) and safety practice (using mask).

## 1.5 Significance of the Study

Dust has a long history of association with disease and known to give adverse health effects on the various organs such as eye, nose, skin and the airways. The occupational related lung diseases are likely due to the deposition of dust in the lung and influenced by the type of dust, period of exposure, concentration and size of airborne dust in the breathing zone (Mengesha and Bekele, 1998). Monitoring the work environment and worker's health would provide evidence of any health impairments. This study was conducted to determine the relationship between dust exposure and respiratory health among quarry workers. Besides, it also helps the workers to understand the effect of dusty working environment and predict possible outcome after the exposure. The outcome of this study will provide a significant insight to the prevalence of respiratory symptom and understanding the risk factors of respiratory disorders. The result of this study lays the platform for the intensive discussion and cooperation to ensure the safety and health of quarry workers. In addition, this study will become useful reference for future researchers to update the basic safety and health and to improve the working condition in the workplace.

### 1.6 Conceptual Framework

Quarry is an open cavity where stone or slate is extracted and deposited of rock such as granite which is mining for use in construction projects (Aigbkhaode *et al.*, 2013). The operation creates large amount of dust which contain silica ranges 20 -70% (Ahmad, 2014). The inhalation of dust containing silica can lead to silicosis, an irreversible lung disease resulting in inflammation of lungs and breathing difficulties which progresses even when exposure end (Ugbogu *et al.*, 2009).

This study was focused on respirable dust exposure which is one of the physical hazards found in the workplace. The study variables are summarised in the conceptual framework (Figure 1.1). Factors that influence respiratory symptoms and lung function can be classified into two; individual factors such as age and smoking habit and workplace factors such as duration of work. Personal protection equipment (PPE) is the last action after all safety measures to eliminate and control hazards in the workplace. PPE can reduce skin contact and inhalation of air pollution. This is determined by the compliance and use of PPE throughout working shift.

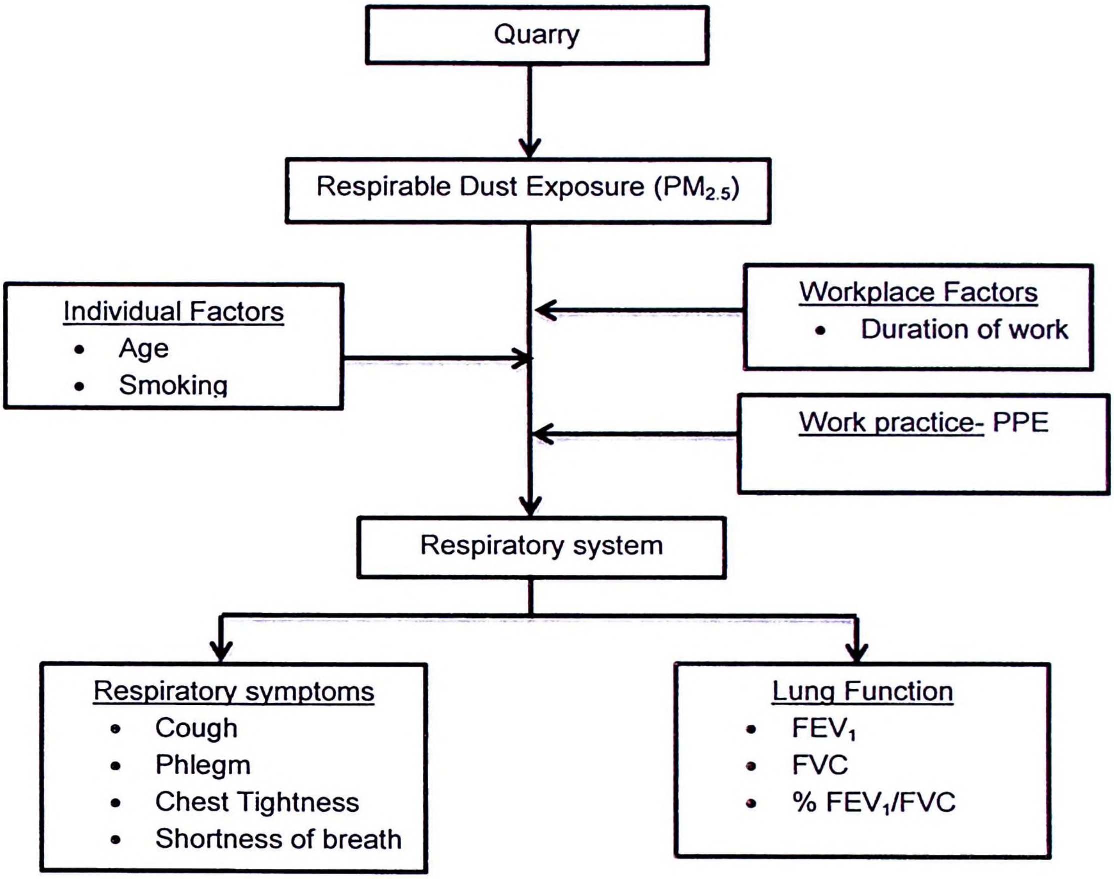


**Figure 1.1**: Conceptual framework

## CHAPTER 2

## LITERATURE REVIEW

### 2.1 Quarrying Process

Quarries are place where rocks, sand, or minerals are extracted from the surface of the earth. They refer to operations where the material is used in construction, whereas open-pit mining often refers to metal mines and opencast mining usually refers to coal (National Geographic, 2016). Quarrying is a form of land use method concerned with the extraction of non-fuel and non-metal minerals from rock (Ukpong, 2012). Stone quarrying is the multistage process. Rock is extracted from the ground and crushed to produce aggregate, then screened into the sizes required for immediate use, or for further processing, such as coating with bitumen to make bituminous macadam (bitmac) or asphalt (Northstones Material, 2016)

In Malaysia, there are two main types of quarries; limestone and granite quarries. Limestone is used as raw material for cement, lime and in the manufacturing of paper, paint, plastic, rubber and glass. Granite has been used as aggregate, dimension stone, flooring tiles in home and commercial buildings also monuments (Zulasmin, 2007). Rocks are classified as limestone and contain up to 40% crystalline silica and granites while 55% crystalline silica. Quartzite and natural sands are normally in the range of 80 - 100% crystalline silica. Recycled concrete should be given a precautionary classification as it is greater than 80% of silica. None of the quarried rocks or minerals can be guaranteed as silica free although many basalt deposits (but not all) are less than 1% of crystalline silica (Mining and Quarrying Occupational Health and Safety Committee, 1998).

Drilling and blasting are important process to get the rock out of the earth. Before undergo blasting, first the holes are drilled in the earth and explosives are placed inside. The explosive are detonated to provide energy for the most efficient blasting. The blasts occur when the explosive are set off free the stone from the quarry wall. The free stone from the quarry wall are loaded by large haul trucks and moved to the rock crusher and divided into different sizes. Depending on the size of the output, the rock may be put through different and smaller sizes of crushers one or more times. As the rocks pass through the crushers, they are moved around the processing plant on conveyor belts. After crushing, comes screening. There are four stages of crushing. Each stage produces progressively smaller sized stones. Screening involves the separation of these small stones into sizes while screens are basically box-frames are usually driven by electric motor (Ogbodo *et al.*, 2013). Some screens are larger to allow the bigger rocks to pass through. The smaller screens let only the small rocks pass through. Rocks get from one place to another by continuously moving on conveyor belts. The conveyors help move rocks in economical way by saving money and time. The storing rocks can be huge piles of rock with some of stockpiles as much as 30 feet high and 300 feet around. Finally the rock is loaded in to trucks for transportation to where they are needed (Vulcan Material Company, 2013). According to Ogbodo *et al.* (2013) the major quarry dust is emitted during crushing and screening. In developing countries, the screening and crushing process done manually thus increases workers exposure to quarry dust.

Residents are living near to quarries potentially be affected by dust up to 0.5 km from the source, although continual or severe concerns about dust are most likely to be experienced within about 100 m of the dust source (Guidelines for Planning Authorities, 2004). The main potential impacts of dust are visual impacts, coating/soiling of property (including housing, washing, and cars), coating of vegetation, contamination of soils, water pollution, change in plant species composition, loss of sensitive plant species, increased inputs of mineral nutrients and altered pH balances. Respirable particles, (i.e. those less than 10 micrometers in diameter), give the potential effects to human health which depend on exposure levels.

## 2.2 Particle Size Fraction: Conventions for Dust Sampling

Dust particles are small dry particles ranging in size from 1 to 100 μm in diameter. Airborne dust depends on their origin, physical characteristics and ambient conditions (Ugbogu *et al.*, 2009). Exposure to any dust in excessive amounts can create the respiratory problem (Petavratzi *et al.*, 2005). Dust emitted from a whole host of operations both manual and mechanical. The use of power tools such as grinding, cutting and sanding create large quantities of dust. However, if not properly managed can cause ill health to employees for prolongs exposure.

The fractions of the airborne particles inhaled and deposited in the various regions depend on many factors. The conventions have been agreed in terms of aerodynamic diameter, consist of dust sampling and depend to the region of interest for the substance and hazard concerned. The American Conference of Governmental Industrial Hygienists (ACGIH) (1999), the International Organization for Standardization (ISO) (1995), and the European Standards Organization (CEN) (1993) have reached agreement on definitions of the inhalable, thoracic and respirable fractions (World Health Organization (WHO), 1999). The conventions only specify the fraction of ambient aerosol (to be collected) and restrict to measure only mass. The conventions were deliberately set-up conservatively (in view of the large inter- and intra-person variation) the actual deposition of particles (and hence true exposure) differs from penetration (Bartley and Vincent, 2011).

Inhalable particulate fraction is the fraction of a dust cloud that can be breathed into the nose or mouth. Examples of inhalable particle include certain hardwood dusts (which may cause nasal cancer), and dusts from grinding lead containing alloys (which can be absorbed and cause systemic poisoning). Thoracic particulate fraction is the fraction that can penetrate the head airways and enter the airways of the lung. For example thoracic particles include cotton and other dusts causing airway disease. Respirable particulate fraction is the fraction of inhaled airborne particles that can penetrate beyond the terminal bronchioles into the gas-exchange region of the lungs. Examples of dusts for which the respirable fraction offers greatest hazard include quartz and other dusts containing free crystalline silica; cobalt-containing and other hard metal dust produced by grinding masonry drill bits; and many others (WHO, 1999; Vincent, 2005).

### 2.2.1 Respirable Dust Exposure

Respirable dust refers to those dust particles that are small enough to penetrate the nose and upper respiratory system and deep into the lungs. Particles penetrate deep into the respiratory system are generally beyond the body's natural clearance mechanisms of cilia and mucous and are more likely to be retained (Mody and Jakhete, 1987). A respirable particle is too small to be seen with the unaided eye. The respirable fraction is the percentage of the inhalable fraction convention, which is to be collected at an aerodynamic diameter in micrometers, given by a cumulative lognormal distribution with a median diameter of 4.25 μm and a geometric standard deviation of 1.5 (CEN, 1993).

## 2.3 Occupational Exposure Limit

Occupational exposures limits are set to prevent or limit the workers' exposure to dangerous substances at work place and to protect them against risks from such material. Exposure standards represent the airborne concentration of a particular substance or mixture that must not be exceeded. There are three types of exposure standard that are 8-hour time-weighted average (TWA); peak limitation and short term exposure limit (STEL) (Safe Work Australia, 2012). The exposure standard is expressed as TWA concentration of a substance for an eight-hour working day and five day working week. Silica and hardwoods are known to be particularly hazardous to the body and are given lower Workplace Exposure Limits (WEL). WELs can be used to show areas and operations where employee exposure is above a known "safe" limit. The quarry workers are potentially dusty operation and have potential to be exposed to respirable airborne dust including respirable crystslline silica. Respirable crystalline silica (RCS) is assigned a workplace exposure limit (WEL) of 0.1 mg/m$^3$ in Schedule 1 of the Control of Substances Hazardous to Health Regulations 2002 (COSHH). The WEL is expressed as an 8-hour time-weighted average (Health Safety Executive, 2008).

The US Occupational Safety and Health Administration's (OSHA) permissible exposure limit (PEL) is 0.10 mg/m$^3$ for an eight hour time weighted average exposure to respirable crystalline silica. National Institute for Occupational Safety and Health (NIOSH) has recommended an exposure limit of 0.05 mg/m$^3$ as a time weighted average for up to 10 hours per day during a 40 hour week (Mannetje *et al.*, 2002; Glass *et al.*, 2003; Esswein *et al.*, 2013). The ACGIH threshold limit value (TLV) for respirable silica (as α quartz) is 0.025 mg/m$^3$ TWA for up to an 8-hr workday (Esswein *et al.*, 2013).

The Factories Act 1948 applies to stone crushing processes and similarly stipulates the effective measures must be taken to prevent inhalation of excessive concentrations of dust. Amendments to this legislation also specifically set the Permissible Exposure Limit of respirable silica at 0.1 mg/m$^3$, in line with exposure limits for Australia, the United States (U.S. Department of Labor, 2011) and many European countries (Maxted, 2011).

In Malaysia, under Factories and Machinery Act (Mineral Dust) Regulation 1989 stated that no employee shall be exposed to crystalline silica at a concentration greater than

0.05 mg/m$^3$ of respirable cristobalite or 0.1 mg/m$^3$ of respirable quartz or 0.05 mg/m$^3$ of respirable tridymite, averaged over an eight-hour period.

## 2.4 Dust Exposure and Health Effect

The health issues related to breathing respirable dust vary widely depending on the type of dust involved and the concentration inhaled (Maxted, 2011). Quarrying operations generate large quantities of dust that cause a variety of respiratory diseases among quarry workers (Wanjiku, 2015). Workers in mines and stone quarries are particularly at risk, with many dying of silicosis or other respiratory illnesses each year (Maxted, 2011).

Pneumoconiosis, the general term given to a range of lung diseases caused by inhalation of variety of organic or inorganic dusts or chemical irritants. It usually appears over a prolonged period of time, typically causes chest tightness, shortness of breath and cough (Encyclopædia Britannica, 2014). Silicosis is the most likely form of pneumoconiosis among mine and quarry workers. Silica, or silicon dioxide ($SiO_2$) is common in rocks and ores, particularly as quartz or sand. Silicosis is contracted by breathing respirable silica dust by its pure crystalline forms. As a result, crushing or blasting rocks with crystalline silica present (is likely leave nearby) workers at high risk of contracting the disease (Maxted, 2011). Prolonged exposure to crystalline silica can also cause chronic obstructive pulmonary disease (Mannetje *et al.*, 2002).

A study conducted by Nwibo *et al.* (2012) in Ebonyi State, Nigeria found respiratory problems among quarry workers were chest pain (47.6%), occasional cough (40.7%), occasional shortness of breath (6.5%) and wheezing (5.2%). A similar study by Olusegun *et al.* (2009) in Abeokuta Ogun State, Nigeria reported that, 26% of the workers suffered predominantly from cough, 20% from catarrh and 15% from sinusitis.

### 2.4.1 Silicosis

Silicosis is a diffuse pulmonary interstitial disease characterized by a fibrotic response in lung parenchyma caused by continual inhalation of crystalline silica ($SiO2$). It is one of the primary pneumoconiosis diseases caused by inhalation of mineral dust (Vyas, 2013; Álvarez *et al.*, 2015). A worker may develop one of three types of silicosis, depending on the airborne concentration of respirable crystalline silica: (1) chronic silicosis, which usually occurs after 10 or more years of exposure at relatively low concentrations; (2) accelerated silicosis, which develops 5 to 10 years after the first exposure; or (3) acute silicosis, which develops after exposure to high concentrations of respirable crystalline silica and results in symptoms within a period ranging from a few weeks to 5 years after the initial exposure (NIOSH, 1992).

The symptoms of accelerated silicosis are similar to those with chronic silicosis, but clinical and radiographic progression is rapid. Fibrosis may be irregular and more diffuse or not apparent on the chest radiograph. Acute silicosis is typically associated with a history of high exposures from tasks that produce small particles of airborne dust with a high silica content, such as sandblasting, rock drilling, or quartz milling (American Thoracic Society, 1997; NIOSH, 2002).

Simple silicosis is usually diagnosed by a combination of a suitable exposure history (for example sandblasting, quarrying, stone dressing, refractory manufacture, or foundry work) and the finding of fine nodules on plain chest film or CT scan. Disease tends to be occurred in upper zones, but the lower zones may be involved in severe cases. By definition the nodules of simple silicosis are no greater than 1 cm in maximum diameter; larger nodules are classified as complicated pneumoconiosis. Many patients with simple silicosis are asymptomatic. Cough may be present, possibly reflecting irritation of tracheal and bronchial nerves by silicotic nodules shortness of breath is not common. In many patients with simple silicosis, pulmonary function is normal or shows only a minor decrease in vital capacity. There is increasing evidence that silica exposure is associated with changes of chronic airflow obstruction (Mossman and Churg, 1998).

Vyas (2013) found that marble cutters and stone cutters are prone to respiratory dysfunctions while working in the dusty environment. Duration of exposure to silica dust predisposing them to suffer from benign pneumoconiosis, silicosis and tuberculosis. When small particles are inhaled daily and retained in pulmonary acinus resulting into genesis of lung diseases due to interaction between silica dust and alveolar macrophages.

In Spain, the prevalences of silicosis have been reported in various industries with risk of silica inhalation: 47.5% in granite quarries in El Escorial, 26% in underground fluorite mines in Asturias, 36% in the slate industry in Galicia and 6% in granite works in Extremadura (Álvarez *et al.*, 2015).

### 2.5 Silica Dust Properties

Silica refers to the chemical compound of silicon dioxide ($SiO_2$), which occurs in a crystalline or non-crystalline (amorphous) form. Crystalline silica may be found in more than one form (polymorphism). The polymorphic forms of crystalline silica are alpha quartz, beta quartz, tridymite, cristobalite, keatite, coesite, stishovite, and moganite (NIOSH, 2002). In most occupational exposures, quartz is the major type of silica involved (Castranova and Vallyathan, 2000) and most common form of crystalline silica (OSHA, 2002). Amorphous silica and silicates are relatively less fibrogenic than crystalline silica (Castranova and Vallyathan, 2000; Sahai, 2003). Rocks such as granite, shale, and sandstones contain as much as 67% quartz (the most common crystalline silica). Thus, mining, blasting, and construction activities may result in significant exposures to silica dust (Mossman and Churg, 1998).

In the case of a-quartz, as well as the other crystalline polymorphs with the exception of stishovite, the silicon dioxide ($SiO_2$) molecules are arranged as a tetrahedral crystalln the presence of water, the surface of silica becomes hydrated to form silanol groups (-SiOH). The high reactivity of crystalline silica to biologic membranes is due to the unique properties of these surface silanol groups. The first theory is -SiOH groups are hydrogen donors, whereas most biologic macromolecules contain lonepair electrons on oxygen or nitrogen that serve as hydrogen acceptors. The formation of hydrogen bonds would result in strong interaction between silica and biologic membranes, resulting in possible damage (Castranova and Vallyathan, 2000).

A second theory is the surface of silica is negatively charged. At pH 7.0, 1 in 30 -SiOH groups would be negatively charged (-SiO-). Negatively charged silica particles would react strongly with scavenger receptors on alveolar macrophages and would activate the generation of reactive oxygen species (ROS) and inflammatory cytokines (Castranova, 1998; Sahai, 2003). A third theory is the cleavage of the silica crystal, as would occur in silica flour milling, rock drilling, and sandblasting, results in the generation of Si and SiO' radicals on the fracture planes, which can induce oxidant damage (Vallyathan *et al.*, 1995; Castranova, 1998). Stishovite is another polymorph of pure crystalline silica that is distinguished by its octahedral structure. Structural differences among these polymorphs are considered to be important in their biologic reactivity, i.e., > quartz > tridymite > cristobalite> coesite > stishovite (Castranova and Vallyathan, 2000; Sahai, 2003).

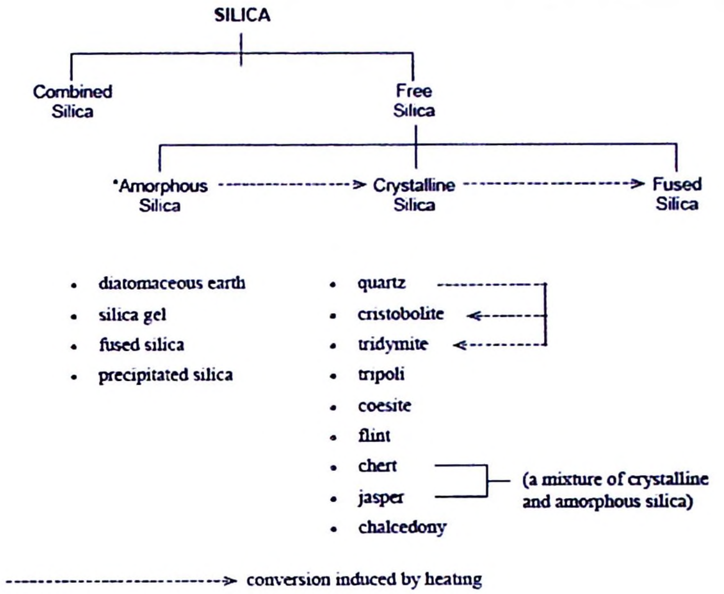


**Figure 2.1** Interrelationships between Forms of Silica
Sources: Industrial Accident Prevention Association (2008)

## 2.6 Routes of exposure

There are four routes substances can enter the body that are inhalation, skin (or eye), absorption, ingestion and injection (Ariens *et al.*, 1976). The major route for the airborne particles is inhalation. The lung with its extensive surface area, high blood flow and thin alveolar epithelium is an important site of contact with substance in environment. The inhalation of dust over periods of time leads to proliferation and fibrotic changes in lungs (Vyas, 2013).

When being inhaled, chemicals are either exhaled or deposited in the respiratory tract. If deposited, damage can occur through direct contact with tissue or chemical may diffuse into the blood through the lung-blood interface. Upon contact with tissue in the upper respiratory tract or lungs, chemicals may cause health effects ranging from simple irritation to severe tissue destruction. Substances absorbed into the blood are circulated and distributed to organs have the affinity for that particular chemical. Health effects might occur in the organs, which are sensitive to the toxicant (University of Nebraska Lincoln Environmental Health and Safety, 2012).

Exposure depends on the air (usually mass) concentration and particle aerodynamic diameter of the dust and exposure time (duration). The dose received is influenced by conditions that affect the uptake (for example, breathing rate and volume) (WHO, 1999). The respirable fraction of the dust, particles generally considered to be smaller than 5μm (millionth of a metre) can penetrate to the innermost reaches of the respiratory tract. These are the alveoli or air sacs where exchange of oxygen and carbon dioxide occurs. Dust particles are removed by white blood cells known as macrophages. Particles of free crystalline silica cause the macrophages to break open (Industrial Accident Prevention Association, 2008).

### 2.7 Respiratory system

The respiratory system plays a vital role in the body, by providing cells with oxygen, as well as excreting carbon dioxide, which can be deadly if allowed to accumulate. The three major parts of the respiratory system are the airways, the lungs, and the muscles of respiration.

#### 2.7.1 Anatomy of respiratory system

The three major parts of the respiratory system all are the airways, the lung and the muscle of respiration (See Figure 2.2: The Respiratory System). The airways (nose, mouth, pharynx, larynx, trachea, bronchi, and bronchioles) allow air to enter the body and into the lungs. The lungs work to pass oxygen into the body, whilst removing carbon dioxide from the body. The muscles of respiration, such as the diaphragm, work in unison to pump air into and out of the lungs whilst breathing (Taylor, 2016).

Functionally, the system consists of two zones that are respiratory zone and conducting zone. The respiratory zone, the actual site of gas exchange, is composed of the respiratory bronchioles, alveolar ducts, and alveoli, all microscopic structures. While, conducting zone includes all other respiratory passageways, which provide fairly rigid conduits for air to reach the gas exchange sites. The conducting zone organs also cleanse, humidify, and warm incoming air. As a result, air reaching the lungs has fewer irritants (dust, bacteria, etc.) than when it entered the body, and it is warm and damp, like the air of the tropics (Marieb and Hoehn, 2013).

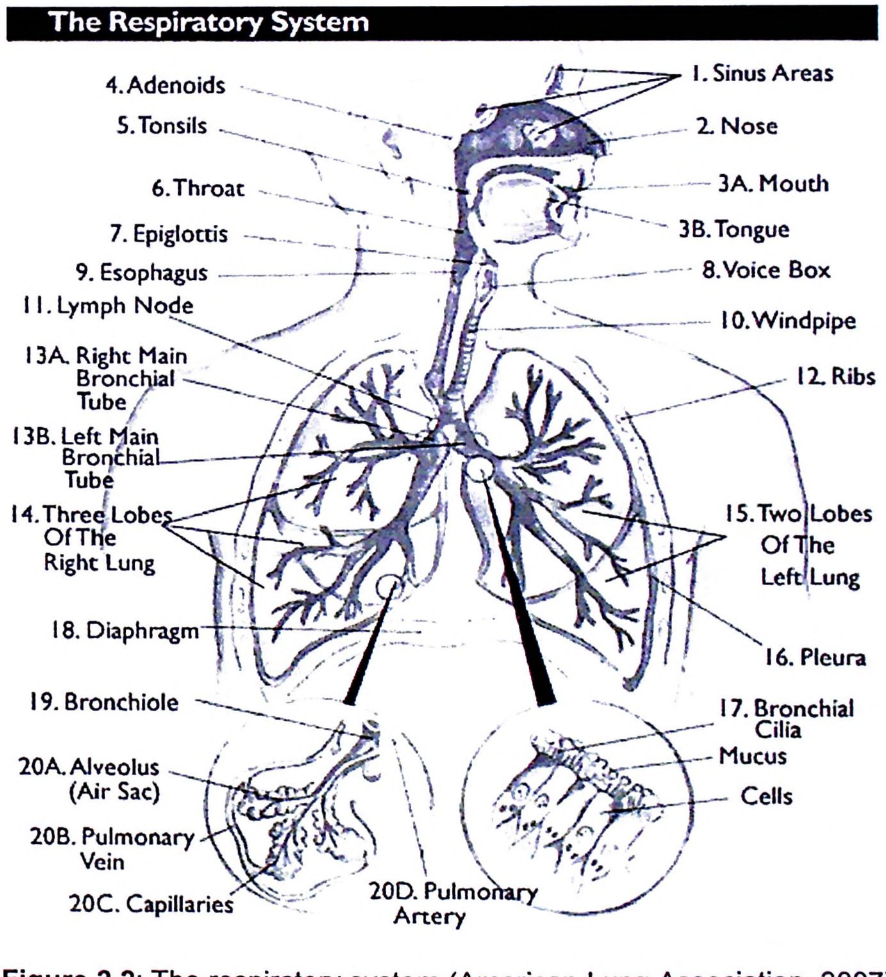


**Figure 2.2**: The respiratory system (American Lung Association, 2007)

### 2.7.2 Physiology of respiratory system

The respiratory system has a complex physiology and is responsible for multiple functions. The movement of air within the lung are referred to as ventilation of lung. The exchange of oxygen ($O_2$) and carbon dioxide ($CO_2$) between alveolar air and lung capillaries, occurs through diffusion down a concentration gradient and dependent on the different partial pressure of each gas (West, 1990). Gases move from high pressure area to low partial pressure area. Because of the differences in partial pressures of oxygen and carbon dioxide in the systemic capillaries & the body cells, oxygen diffuses from the blood and into the cells, while carbon dioxide diffuses from the cells into the blood (Patel *et al.*, 2013).

Oxygen is transported by the blood either in combination with haemoglobin (Hb), oxyhaemoglobin ($HBO_2$), or a tiny amount is dissolved in plasma (Marieb and Hoehn, 2013). During rest, 95% of all oxygen delivered to tissues is transported in combination with haemoglobin, while during exercise this value may exceed 99%. The amount of $O_2$ combined with haemoglobin depended on blood partial pressure of oxygen ($pO_2$) to which the haemoglobin is exposed. When Hb is fully converted to $HBO_2$, it is fully saturated. When both forms exist haemoglobin is partially saturated. Figure 2.3 showed the oxyhaemoglobin dissociation curve. The normal curve for adult haemoglobin is shown in red, with dots showing the normal values in arterial and venous blood. $P_{50}$, the $pO_2$ at which haemoglobin is 50% saturated, is indicated by the arrow showing a normal value of 3.5 kPa. The curve can be shifted to the left or right by the factors listed in the boxes, but these physiological changes in adults are small compared with the increased oxygen binding achieved by fetal haemoglobin (purple line) (Thomas and Lumb, 2012). The rate of saturation differs, depending on the $pO_2$. At higher levels, the rate of increase is less. This explains why people can still perform well at low oxygen concentration (for example, at high altitudes or cardiac and pulmonary diseases). For example, at a $pO_2$ of 40 mm Hg, Hb saturation is 75% saturated. This is the point which represents mixed venous blood. Damage to the respiratory system can displace the oxygen-haemoglobin dissociation curve to the left. This means that the respiratory system has to work harder to maintain the oxygen levels. In turn, this means that lungs more vulnerable to further adverse exposures (Nurul, 2009).

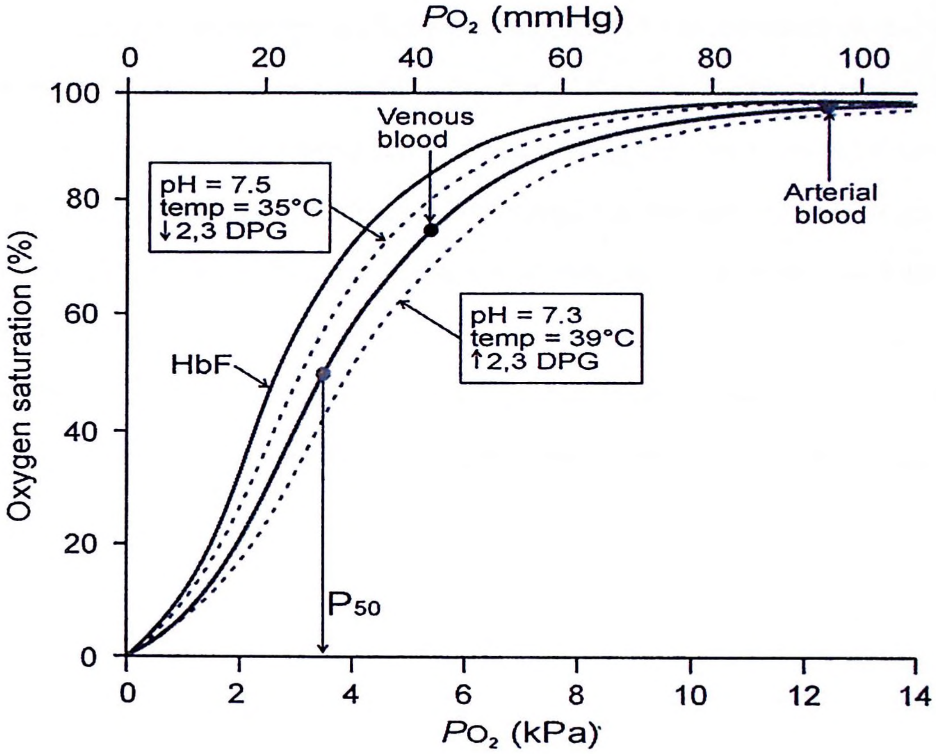


**Figure 2.3**: The oxyhaemoglobin dissociation curve.

Sources: Thomas and Lumb (2012)

### 2.7.3 Mechanism of Respiration

There are four stages of respiration which are breathing, external respiration, internal respiration and cellular respiration. The first stage, breathing, involves two basic processes identified as inspiration. It moves air the outside of the body into the lung and expiration air from the lung back to the outside of the body area. The second stage, external inspiration, is the gas exchanges process of oxygen and carbon monoxide between air and blood. The third stage, internal inspiration, is the gas exchange processes between blood and tissue fluid. Lastly, cellular respiration is the series of energy releasing chemical reaction that occurs within the cells (Naemah *et al.*, 2015).

During inspiration the intercostal muscles between the ribs pull them upwards and outward. The muscular diaphragm contracts and flattens. The movements of ribs and diaphragm lead the chest expands and the volume of thoracic cavity increased. The simultaneous expansion of the pleural cavities surrounding the lungs creates a partial vacuum. The result is rushing in of external air through the trachea into the lungs. To exhale air, the diaphragm and external intercostal muscles relax while the internal intercostal muscles contract to reduce the volume of the thorax and increase the pressure within the thoracic cavity. The pressure gradient is now reversed, resulting in the exhalation of air until the pressures inside the lungs and outside of the body are equal (Taylor, 2016).

### 2.8 Pulmonary Function Test

Exposure to dust can impair lung function and causes respiratory and other symptoms. The length of the exposure is a predisposing risk factor (Urom *et al.*, 2005). Exposure to respirable crystalline silica, a common contaminant of mining and quarry operations, results in the lung damaging diseases known as silicosis and chronic obstructive pulmonary disease (COPD) (NIOSH, 2002). Long-term exposure to respirable crystalline silica can lead to increas risk of lung cancer. Pulmonary function tests (PFT's) are breathing tests to find out the air move in and out of the lungs and how well oxygen enters to the body (American Thoracic Society, 2014).

Pulmonary function test are designed to identify and quantify defects and abnormalities in the function of the respiratory system. The tests can also answer other clinical question but it cannot be expected to lead to a clinical diagnosis (for example, pulmonary fibrosis or emphysema). Test results must be evaluated based on history, physical examination, chest radiograph, computed tomography scan, as well as pertinent laboratory findings. Nevertheless, some test patterns strongly suggest the presence of certain conditions, such as pulmonary fibrosis (Hyatt *et al.*, 2014).

Spirometry is the most frequently used to measure the lung function and is volume against time. In the occupational health setting, spirometry plays a critical role in the primary, secondary, and tertiary prevention of workplace-related lung disease (Townsend *et al.*, 2011). The most important aspects of spirometry are the forced vital capacity (FVC). FVC is the volume delivered during an expiration made as possible starting from full inspiration. The force expiratory volume in one second ($FEV_1$), is the volume deliver in the first second of and FVC manoeuvre and $FEV_1$/FVC ratio which gives index of airflow limitation (Ranu *et al.*, 2011).

Valid test is achieved (see Figure 2.4) when Flow-volume curve (left) emphasizes start of test, rising immediately to a sharp peak and smoothly descending to zero flow. Volume-time curve (right) emphasizes end of test, initially rising rapidly, and then gradually flattening out and reaching one second of no visible volume change, at the FVC plateau (Townsend *et al.*, 2011).

Once a valid test results have obtained the interpretation of worker respiratory health depends on two factors. First, selecting and consistently using appropriate reference values to define the normal range for FVC, $FEV_1$, and $FEV_1$/FVC; and second, follow an appropriate algorithm to categorize the worker's spirometry results as normal or abnormal (OSHA, 2013). Test results are given as measured values and as percents of predicted values. The predicted values and lower limits of normal have been determined in studies population of people without physiologic lung impairment. Regression equations have been developed that include the person's age, height, and sex as variables (although debate exists as to which regression equations are most accurate). The predicted values therefore depend on his or her age, height, and sex (Al-Ashkar *et al.*, 2003).

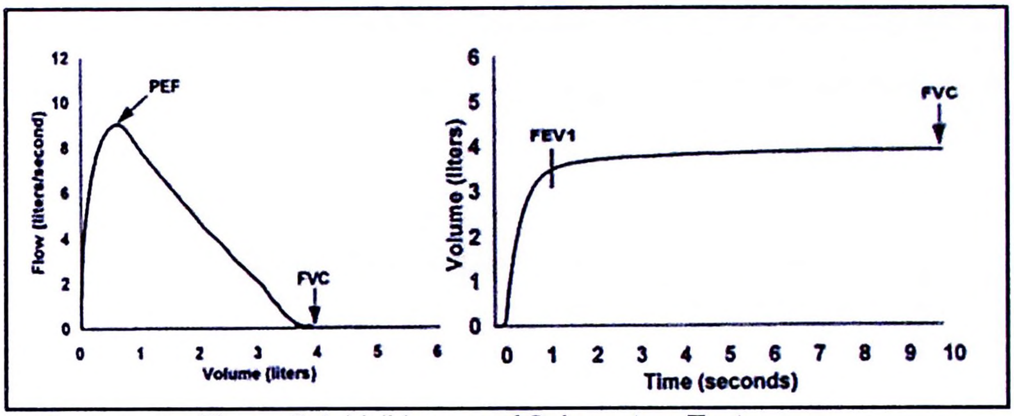


**Figure 2.4**: Valid curve of Spirometery Test

Source: Townsend (2011).

### 2.8.1 Type of ventilitory detect

Spirometry interpretations should specify whether the worker's lung function is in the normal range, or shows an obstructive, restrictive, or mixed impairment pattern (see Figure 2.11) (Johns and Pierce, 2008).

- Obstructive ventilatory defects: A reduction of $FEV_1$ in relation to the forced vital capacity will result in a low $FEV_1/FVC$ (e.g. asthma and emphysema). The lower limit of normal for $FEV_1/FVC$ is around 70-75% but the exact limit is dependent on age. In obstructive lung disease the FVC may be less than the slow VC because of earlier airway closure during the forced manoeuvre. This may lead to an overestimation of the $FEV_1/FVC$. Thus, the $FEV_1/VC$ may be a more sensitive index of airflow obstruction.
- Restrictive ventilatory defects: The $FEV_1/FVC$ ratio remains normal or high (typically > 80%) with a reduction in both $FEV_1$ and FVC (e.g. interstitial lung disease, respiratory muscle weakness, and thoracic cage deformities such as kypho-scoliosis).