Industrial Health 2009, **47**, 43–49 **Original Article**

Evaluation of Occupational Exposures to Respirable Dust in Underground Coal Mines

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Received July 11, 2007 and accepted September 4, 2008

Abstract: Dust can be produced by almost all mining operations in underground coal mines and seen all around the mine. Different occupational groups get exposed to different dust levels and in order to minimize the probability of developing coal workers' pneumoconiosis (CWP), it is necessary to investigate the workers exposed to dust. This study aimed to evaluate the dust concentration conditions in underground coal mines and also the occupational health risks associated with exposures to respirable dust. The data obtained from the dust measurement studies conducted in various underground coal mines between the years 1978–2006 was evaluated by using analysis of variance (ANOVA) and Tukey-Kramer procedure. In the statistical analyses, the comparison of dustiness between mines and their mining regions were made by using the average dust concentration values. In addition, the numbers of workers with doubtful pneumoconiosis diagnosis were evaluated according to the occupational job category by using the number of the workers with the job illness. It was concluded that the production regions have the higher dust concentration levels and the CWP is mostly diagnosed in the workers working in production regions.

Key words: Dust, ANOVA, CWP, Underground mining

Introduction

Working conditions in underground mining are associated with a considerable number of health risk factors, such as a high physical workload, noise, vibration, radiation exposure, diesel exhaust, high temperature and humidity conditions and exposure to dust and gas phase hazardous substances[1–3]. Dust is generated and dispersed into the mine air through rock breakage, rock loading, transportation and unloading and through the flow of ventilation air. Dust is produced in all rock-breaking processes. The quantity of potentially airborne dust produced is related to the quantity of rock broken[4]. Coal miners are typically exposed to mixed coal dust in the workplace. Significant exposure to coal dust may occur especially during underground coal mining[5]. Inhalation of coal mine dust is associated with the development of pulmonary disease in miners[6]. The factors that determine the harmfulness of an airborne dust are composition, concentration, particle size, exposure time and individual susceptibility[7]. The International Organization for Standardization (ISO), the American Conference of Governmental Industrial Hygienists (ACGIH), and the European Committee for Standardization (CEN), agreed on a common definition of the respirable aerosol fraction and the international standard ISO7708 (1995) is commonly accepted by industrial hygienists in determining health hazards from inhaled aerosol particles[8, 9]. According to ACGIH and ISO7708, particles have been classified as coarse, medium, and fine ranges. Particles over 4 μm are classified as coarse particles, those between 1 and 4 μm are medium and below 1 μm are designated as fine particles[10]. Inhalated coal dust can deposit in lungs and can lead to the development of several diseases in exposed workers. Coal workers' pneumoconiosis (CWP), a disease defined in terms of coal dust deposition in the lungs, was observed to be highly common in coal miners and is caused by inhalation and retention of coal mine dust[4, 5]. A number of studies showed that in coal workers, up to 30 g of total dust may be found in the lungs, with an accumulation rate of 0.4–1.7 g of dust retained each year[11]. The concentration of respirable coal

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dust, the period of exposure and free silica content are important factors associated with pneumoconiosis risks[12]. Diagnosis of CWP is generally based on chest X-ray findings and a history of working in coal mines (usually for 10 or more years)[13]. The incidence of CWP is affected by coal rank. CWP is five times more prevalent in anthracite miners than for miners of lower rank coal. Data indicate a direct relationship between the mass of respirable coal mine dust inhaled and the incidence and severity of CWP[6]. Different categories of workers get exposed to different dust levels depending on many factors like type of workings, activity, period of exposure, etc.[14]. Workers in the coal mine had high exposure to respirable dust and quartz, especially the development team that creates mining paths for the miners to extract coal[15]. Kizil and Donoghue[16] searched of personal respirable coal dust measurements recorded by the Joint Coal Board in the underground longwall mines of New South Wales from 1985 to 1999. 11,829 measurements from 33 mines were analyzed and the results given for seven occupational groups. One of the aims of the analysis was to estimate the future prevalence of coal worker's pneumoconiosis. Ross and Murray[17] explained the relationship between mining and occupational lung disease such as CWP by using the prevalence data.

In this study, the comparisons of dustiness between the different coal mines and subsections and also the relation between dust exposure and CWP were investigated by using the Analysis of Variance (ANOVA) and Tukey-Kramer procedure.

Methods

Subjects

The data concerning dust measurements carried out in different underground coal mines between the years 1978–2006 were examined to evaluate the dust concentration conditions. The personnel working in the mines have made three kinds of dust measurement to fight against dust. These are periodic measurements, precaution measurements and investigation measurements. Periodic measurements are the regular measurements carried out once a month in production regions such as longwall faces and heading faces, once in a period of four months in gate roads and stone drifts and once in a period of six months in underground haulage roads. 40,823 periodical stationary measurements were made in various underground working places between 1978–2006 yr. The sampling locations have been classified such as production regions (i.e. heading faces, longwall faces), gate roads, stone drifts and haulage roads and numbered by the enterprises. The dust samplers were placed to the air flow direction and at breathing level of workers. Respirable dust conditions of working environment of mines were determined by gravimetric dust equipment Casella 113 A type. In Turkey coalmines, permissible limit of dust concentration is 5 mg/m^3. Precaution measurements are the measurements carried out in various districts where the dust concentration is more than 5 mg/m^3. There is not a regular period. Investigation measurements are the measurements, apart from the periodic and precaution measurements, carried out in newly constructed mining region when there is a claim respecting the issue. When the dust concentration is more than 5 mg/m^3, firstly the measurement is repeated with other different dust measurement equipments. Following the detection of the basis of the problem, production must be stopped according to the regulations, and only studies related to fighting with dust is allowed to continue.

It has been standardized for the workers in the mines to have chest X-ray. Additionally, lung function tests are also administered. The tests are helpful in elaborating the damage and effect of the dust on workers. The advanced tests are applied to the workers with doubtful CWP diagnosis during the periodic inspection of the doctors working for "Health Directorate". The workers with doubtful CWP diagnosis are registered and kept safe and temporarily sent to locations without dust.

Description of the enterprises

The enterprises are located in the northwestern Turkey on the Black Sea coast and from mining operations point of view; these are the most important production areas in Turkey. It is predicted that the coal reserves in coal basins are about 1.1 billion tons of coal and their area extent is 13,000 km^2. The proven reserves include the seams which are present to a depth of 1,200 m, thicknesses varying between 1 and 10 m. The total coal seam thickness is about 40 m[18]. The currently applied methods in the mines are longwall caving and wholly manual. The main ventilation methods are the exhausting systems. The number of persons employed in the mines and production per year are shown in Fig. 1.

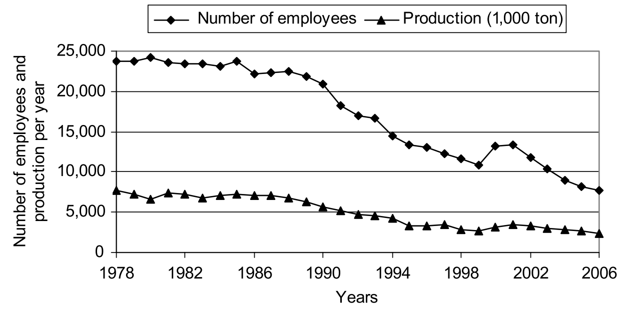

Fig. 1. The total numbers of employees and production per year between 1978–2006.

Statistical analysis

The technique of analysis of variance (ANOVA) was applied to dust measurement values obtained from different underground coal mines. ANOVA is the name given to the approach that allows using sample data to test whether the values of two or more unknown population means are likely to be equal[19].

The main idea of ANOVA is to compare variation within each group to variation between the groups; if the groups vary considerably from one group to another in comparison to the within group variation, it can be rejected the null hypothesis that all the groups have similar levels of the response variable[20]. The two-way ANOVA is a procedure that examines the effects of two independent variables concurrently[21]. In two-way ANOVA, if the factor A has h levels and the factor B g levels, in a balanced design without replication, there will be hg treatment combinations. Assuming that for both factors the levels used are the only ones of interest, then a parametric model is appropriate. The model can be given as follows[22, 23].

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \quad i = 1,\ldots\ldots, h \; ; \; j = 1,\ldots\ldots, g \qquad (1)$$

Where ;

y_{ij} : the response obtained when factor A is at level i and factor B is at level j,

μ : represents the overall mean,

α_i : represents the effect of level i of factor A,

β_j : represents the effect of level j of factor B,

ε_{ij} : represents the random error term.

Results

The dust measurements data from the years 1978 to 2006 were investigated to evaluate dust exposures. The sampling locations were classified, such as heading faces, longwall faces, gate roads, stone drifts, and haulage roads. Dust measurement data obtained from the gravimetric samplers at the five sampling locations were gathered for seven underground coal mines. The mean dust concentration values (mg/m^3) and standard deviations (SD) are given in Table 1.

Table 1 shows the mean dust concentration levels of five major mining regions. Heading faces were found to be the dustiest units producing a mean dust level of 2.39 mg/m^3 and a range of 0.97–3.55 mg/m^3. Longwall faces are the next dusty units of the underground coal mining producing a mean dust level of 2.08 mg/m^3 and a range of 1.45–3.04 mg/m^3, followed by gate roads (0.35–2.06 mg/m^3), haulage roads (0.62–1.66 mg/m^3), and stone drifts (0.82–1.20 mg/m^3).

For the data given in Table 1, whether these results indicated a significant variation between the mines or between the mining regions was investigated. In order to make simultaneous comparisons between the mean values and also to determine whether a significant relation exists between variables, the "two-way ANOVA" was used.

The general format of output for this type of analysis is an ANOVA table, which contains basic information about the analysis. The obtained results are given in Table 2.

Since the purpose of this analysis is to determine if there is a significant difference in the effects of the mines or mining regions, the following hypothesis can be written for the mines;

$$H_o : \alpha_1 = \ldots\ldots = \alpha_7 = 0$$
$$H_1 : \alpha_1 \neq \ldots\ldots \neq \alpha_7 \neq 0$$

As usual, the null hypothesis is one of no difference between the levels whereas the alternative hypothesis is that at least some of them differ[22]. From the F-distribution table, the critical value F0.95 (6,24) is 2.51. Since the critical value exceeds the calculated F-value given in Table 2, the alternative hypothesis is rejected and it is

Table 1. Dust concentrations (mg/m^3) in different regions of underground coal mines

Mines	Mining Regions					Number of data	Mean	SD
	Heading faces	Longwall faces	Gate roads	Stone drifts	Haulage roads			
Mine 1	2.58	2.58	1.86	0.82	1.25	3,917	2.08	0.42
Mine 2	3.55	1.61	2.06	1.10	1.28	5,840	1.78	0.50
Mine 3	0.97	1.45	1.30	1.06	0.62	8,615	1.21	0.18
Mine 4	2.53	2.47	1.32	1.13	1.58	9,735	1.92	0.33
Mine 4.1	3.22	3.04	0.81	0.84	1.36	4,266	1.89	0.59
Mine 4.2	1.47	2.09	1.98	1.20	1.66	5,466	1.95	0.24
Mine 5	1.64	1.87	0.35	0.98	0.76	2,984	1.68	0.45
Number of data	3,617	18,669	10,370	4,265	3,902			
Means	2.39	2.08	1.43	1.06	1.16	Total data : 40,823 General mean : 1.75 mg/m^3		
SD	0.39	0.24	0.26	0.06	0.16			

Table 2. Two-way ANOVA table for the dust concentrations dataset

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Values
Mines	3.81	6	0.64	2.16
Mining regions	9.15	4	2.29	7.78
Error	7.05	24	0.29	
Total	20.01	34		

concluded that the dust levels at the mines do not differ significantly.

Similarly, the following hypothesis can be written for mining region factors;

$H_o : \beta_1 = ... = \beta_5 = 0$

$H_1 : \beta_1 \neq .... \neq \beta_5 \neq 0$

From the F-distribution table, the critical value F0.95 (4,24) is 2.78. Since the calculated F-value is greater than the critical value, then the null hypothesis of no difference between the levels of mining region factors is rejected and the alternative hypothesis is accepted. Therefore, it can be said that there is a difference in the mining region level treatments at a significance of $\alpha = 5\%$ level. If the null hypothesis is rejected, the Tukey-Kramer procedure can be used to determine which population means have statistically significant differences from the others and compare all means of groups simultaneously. The critical range in Tukey-Kramer procedure is calculated to following equation[24].

$$\text{Critical Range} = q_u\sqrt{\frac{\text{MSE}}{r}} \tag{2}$$

Where q_u is the value obtained from Studentized Range Distribution Table, Mean Square Error (MSE) is obtained from the ANOVA output table and r is the number of levels[24, 25].

The q_u value was found from the table for the 0.05 level of α and critical range was calculated as 0.85. The mean values of the dust concentrations according to the mining regions have been calculated and given in Table 1. In order to make multiple comparisons in the Tukey-Kramer procedure, it is required to calculate the absolute difference between the means of the two groups. If the absolute difference between the sample means exceeds the critical range, a pair is considered significantly different[25]. The absolute differences between the two groups were calculated and given in Table 3.

In the first set of the Tukey-Kramer procedure's output, the mean of the dust concentration of heading faces was subtracted from the longwall faces' mean. Because the absolute difference (0.31) did not exceed the critical range (0.85), it can be said that the dust concentration levels of heading faces are not significantly different than longwall faces. The means for heading faces and gate roads are statistically different because the absolute difference (0.96) exceeded the critical range (0.85).The highest absolute difference (1.33) is between heading faces and stone drifts. All of the comparisons were carried out by using the Tukey-Kramer multiple comparison procedures and it was found that the heading faces produce the highest dust concentration levels and the stone drifts produce the lowest dust levels. The majority of dust particles in mines are composed of mineral fragments. Mineral dusts are formed whenever any rock is broken by impact, abrasion, crushing, cutting, grinding or explosives. The main production methods of the mines are quarrying by hand, pneumatic-pick winning method, drilling-blasting and loading. Therefore, it can be said that the production regions such as heading faces have the higher dust concentration levels than the other units. The other units can be put in order as longwall faces, gate roads, haulage roads and stone drifts.

In order to investigate the degree of occupational exposures to respirable coal mine dust, the occupational job category was divided into three groups such as production workers, gate road-stone drift workers and haulage workers. The common responsibilities of these occupa-

Table 3. Multiple comparisons of the mining regions with Tukey-Kramer procedure

Comparison	Absolute Difference	Critical Range	Results
Heading faces to Longwall faces	0.31	0.85	Heading faces not significantly different than longwall faces
Heading faces to Gate roads	0.96	0.85	Heading faces significantly different than gate roads
Heading faces to Stone drifts	1.33	0.85	Heading faces significantly different than stone drift
Heading faces to Haulage roads	1.23	0.85	Heading faces significantly different than haulage roads
Longwall faces to Gate roads	0.65	0.85	Longwall faces not significantly different than gate roads
Longwall faces to Stone drifts	1.02	0.85	Longwall faces significantly different than stone drifts
Longwall faces to Haulage roads	0.92	0.85	Longwall faces significantly different than haulage roads
Gate roads to Stone drifts	0.37	0.85	Gate roads not significantly different than stone drifts
Gate roads to Haulage roads	0.27	0.85	Gate roads not significantly different than haulage roads
Stone drifts to Haulage roads	0.10	0.85	Stone drifts not significantly different than haulage roads

tional job groups can be given as coal excavations, support and filling for production workers; drilling and blasting, shaft, gate road and stone drift excavations for gate road-stone drift workers; and loading and removing coal from mines for haulage workers. The numbers of workers with doubtful CWP determined by the coal worker's X-ray surveillance programs during the period between 1985–2003 are given in Table 4[26].

The main factor under investigation was the occupational job groups. The numbers of workers who had doubtful CWP were evaluated by using the technique of ANOVA for two-way classification. Since the purpose of this analysis is to compare the risk of CWP between the occupational jobs categories within the mines, the following hypothesis can be written;

$H_o : \beta_1 = \beta_2 = \beta_3 = 0$
$H_1 : \beta_1 \neq \beta_2 \neq \beta_3 \neq 0$

The calculated value of F is compared with the critical value ($F_{1-\alpha}$) and $F > F_{1-\alpha}$ then the null hypothesis of no difference between the factor levels is rejected at the specified level α and the alternative hypothesis is accepted[22]. Since the calculated value of F, 9.07, is greater than the critical value F0.95 (2,8)=4.46, the null hypothesis of no difference between the number of the workers that have doubtful CWP is rejected and the alternative hypothesis at the 5% level is accepted. Therefore, it could be said that the number of workers who had doubtful CWP diagnosis changed according to the occupational job categories at the 0.05 significance level between 1985–2003 yr.

Because the means of the job groups were not equal, which population means were significantly different from the others was investigated. Analysis of variance is used to compare the means with any populations. Since the null hypothesis is rejected, the Tukey-Kramer procedure can be used to determine which population means have statistically significant differences from the others and compare all means of groups simultaneously. The q_u value was found from the table for the 0.05 level of α and critical range was calculated as 75.46. In order to make a multiple comparison by using Tukey-Kramer procedure, the mean values of the number of the workers who have doubtful CWP diagnosis according to occupational job categories were calculated and given in Table 4. The absolute differences between the two groups were calculated and shown in Table 5.

Tukey-Kramer procedure showed that there is a significant mean difference only between production workers and gate road-stone drift workers because the absolute mean differences (112.4) were greater than the critical range (75.46). No significant mean differences were revealed between the others. Therefore it can be said that there is a significant difference between production regions and gate roads-stone drifts at 5% level of significance and the workers who have doubtful CWP diagnosis mostly exist in production regions such as longwall and heading faces.

Table 4. The number of workers with doubtful CWP according to occupational job category

Mines	Occupational Job Category		
	Production workers	Gate road and stone drift workers	Haulage workers
Mine 1	112	71	92
Mine 2	266	169	223
Mine 3	377	239	312
Mine 4	664	421	551
Mine 5	117	74	100
Mean	307.2	194.8	255.6

Discussions

Mean respirable dust concentrations in the mines (Table 1) showed lower values than the prescribed Turkish standard of 5 mg/m^3. According to the statistical analysis made to determine whether there is a significant difference in the effects of the mines, because the critical value (2.51) exceeds the calculated F-value (2.16) given in Table 2, it can be said that the mean values of dust concentration in the mines of the enterprises were the same at a significance of α = 5% level. The reason

Table 5. Tukey-Kramer multiple comparisons for the occupational job groups

Occupational Job Groups	Absolute difference	Critical range	Interpretation
Production workers to Gate road-stone drift workers	112.4	75.46	Production workers significantly different than gate road-stone drift workers
Production workers to Haulage workers	51.6	75.46	Production workers not significantly different than haulage workers
Gate road-stone drift workers to Haulage workers	60.8	75.46	Gate road-stone drift workers not significantly different than haulage workers

of the same concentration values may be explained by using the same production method in the coal mines. The mean dust concentration values of heading faces, longwall faces, gate roads, stone drifts and haulage roads were found to be 2.39, 2.08, 1.43, 1.06 and 1.16 mg/m^3 respectively having a range between 0.97–3.55, 1.45–3.04, 0.35–2.06, 0.82–1.2 and 0.62–1.66 mg/m^3 for these mining regions. In respect of the statistical analysis made to investigate if there is a significant difference in the effects of the mining regions, since the calculated F-value (7.78) given in Table 2 is greater than the critical value (2.78), it can be said that the mean values of the dust concentration in different mining regions of the mines are different from each other. Because there is a difference in the mining region level treatments at a significance of $\alpha = 5\%$ level, the Tukey-Kramer multiple comparison procedures were used. All of the comparisons were carried out by using the Tukey-Kramer multiple comparison procedures (Table 3) and it was found that the heading faces produce the highest dust concentration levels. The other dust producing units can be put in order as longwall faces, gate roads, haulage roads, and stone drifts.

The occupational job category was divided into three groups such as production workers, gate road-stone drift workers and haulage workers, and it was aimed at comparing the risk of CWP between the occupational jobs categories within the mines. Since the calculated F-value (9.07) is greater than the critical value (4.46), it can be said that the number of workers with doubtful CWP diagnosis changed according to the occupational job groups at the 0.05 significance level between 1985–2003 yr. In the first set of the Tukey-Kramer procedure's output (Table 5), the mean number of production workers with doubtful CWP was subtracted from the mean number of gate road-stone drift workers with doubtful CWP. Because the absolute difference (112.4) exceeded the critical range (75.46), it can be said that there is a significant difference between production workers and gate roads-stone drifts workers at 5% level of significance. The means for production workers and haulage workers, and gate road-stone drift workers and haulage workers are not statistically different because the absolute differences did not exceed the critical range. According to the analysis, the regions where the numbers of workers with doubtful CWP diagnosis are the most are the production regions such as longwall or heading faces. The workers suffering from the disease and also workers at high risk of having the disease must be kept in safe regions. Necessary arrangements must be implemented for the quick detection of the disease.

Conclusions

The objectives of the study were to evaluate the dust concentration conditions in the working areas as well as the occupational health risks associated with exposures to respirable dust. According to the available dataset of dust levels for the underground coal mining regions and statistical analyses, it can be said that the heading faces produce the highest dust concentration levels. The other dust-producing units can be put in order as longwall faces, gate roads, haulage roads, and stone drifts. The statistical analysis presented in the study indicated that production workers are exposed to higher dust concentration levels than the other category of workers and also, the workers who have doubtful CWP diagnosis mostly exist in production regions such as longwall and heading faces. Overexposure of the production workers to respirable dust can cause serious or fatal respiratory disease. For this reason, water should be used to suppress the dust in longwall and heading faces and additionally, precautions such as drilling with water, water injection to the seam before production works, suppression of dust during coal transportation, regular measurements of the dust concentration, and usage of personal protective masks should strongly be applied to fight against dust in places where it is not sufficient enough to suppress the dust. Although the mean respirable dust exposure in the underground mining regions was found to be below the prescribed Turkish standard of 5 mg/m^3, in order to minimize the risk of CWP among workers, the permissible dust levels in Turkey coalmines should be reduced.

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