

# Determination of the Friction Factors in Potash Mines

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**Abstract**—The friction factor is an essential parameter to take into account for modelling the ventilation system. One of the principal features that define the friction factor is the roughness, which not only does it have influence on the airway resistance, but it has also a direct bearing on the rate of heat transfer between the rock and the airstream. In this paper, the characteristic friction factors of a potash mine exploited using a room and pillar method has been determined by means of the Chezy–Darcy and Atkinson equations. The results give an impulse to achieve standardized friction factor values in potash mines very useful for future mining ventilation surveys.

*Keywords:* Mining ventilation, friction factor, potash mine, room and pillar exploitation method.

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## INTRODUCTION

The knowledge of the ventilation system and the parameters that define its behaviour is crucial for modelling it [1]. Among all of them, one of the most important aspects to take into account is the friction factor, which will be basically affected by the exploitation method, geometric characteristics of the tunnels and physic conditions of the mine [2]. These factors have a huge influence to the resistance against the flow of the air through the airways [3]. However, there is little information about potash exploitations, being mainly focused on coal and metal mines.

This paper give insight of the friction factors in an underground potash mine that uses continuous mining machines to exploit the mineral and carrying it to the surface through a conveyor belt system. These kinds of mines are very deformable due to the pressure from the surrounding rock, producing a considerable roughness in the surface of the galleries. This roughness can also be caused for the exploitation method, the temperature and the humidity grade.

One of the first studies concerning friction factors in mining was done by McElroy [4], which was based on data of the pressure loss collected from coal and metal mines. Many subsequent related studies adding data and determining new values have been published [5–11], even with the goal to standardise the friction factors [12], but there is still a lack of data for other exploitations than metal and coal mines.

### 1. VENTILATION THEORY

Frictional pressure drop is an essential parameter to know the ventilation conditions in an underground mine. It can be obtained using the equation below, which is a form of the Chezy–Darcy expression:

$$p = fL \frac{\text{Per}}{A} \rho \frac{u^2}{2} \text{ (Pa)},$$

where  $f$  is the dimensionless coefficient of friction; Per is the airway perimeter, m; A is the area, m<sup>2</sup>;  $\rho$  is the air density, kg/m<sup>3</sup>;  $u$  is the air velocity, m/s; L is the length of the airway, m.

Later on, it was adapted by Atkinson to the well-known Atkinson equation, expressed in frictional pressure drop:

$$p = kL \frac{\text{Per}}{A} u^2 \text{ (Pa)},$$

where k is the friction factor, kg/m<sup>3</sup>.

The same equation can also be showed in terms of resistance, using the square law, and taking into account any other air density inside the mine due to pressure or temperature factors [13, 14]:

$$R = \frac{P}{Q^2} = kL \frac{\text{Per}}{A^3} \frac{\rho}{1.2} \text{ (Ns}^2/\text{m}^8\text{)},$$

The Atkinson friction factor is not a constant value, it varies with the Reynolds Number. However, the flow of the air in the vast majority of underground places is turbulent in nature except in few cases such as behind the stopings [15]. The Von Kármán equation gives a relationship with the friction factor from the Atkinson expression for turbulent flows. The equation is applicable to circular and non-circular airway, by means of the hydraulic mean diameter calculated with the following relationship  $Dh = 4 A/\text{Per}$ :

$$f = \frac{2k}{\rho} = \frac{1}{4 \left[ 2 \log_{10} \left( \frac{Dh}{e} \right) + 1.14 \right]^2} \text{ (Dimensionless)},$$

where  $Dh$  is the hydraulic mean diameter of the tunnel, m;  $e$  is the height of the roughening, m.

In addition, the airflow also suffers shock losses due to obstacles in the ventilation circuit like direction changes, machines, conveyors, etc. All these elements are independent of the roughness and it is not possible to include it in the friction factor. However, it can be used the equivalent length concept:

$$\text{Leq} = \frac{0.15X}{k} Dh,$$

where  $\text{Leq}$  is the equivalent length, m;  $X$  is the shock loss factor.

The shock loss factor  $X$  is experimentally determined [4, 8, 14], adding an equivalent increase in the length of the tunnel where the air flows [17]. The length increase will vary depending on the type of obstacle [18], obtaining a corrected Atkinson equation:

$$R = k(L + \text{Leq}) \frac{\text{Per}}{A^3} \frac{\rho}{1.2} \text{ (Ns}^2/\text{m}^8\text{)}.$$

### 3. METHODOLOGY

Achieving a proper ventilation system planning not only does it need a good knowledge of the ventilation laws, but it is also necessary an updated database of the ventilation features [17]. For this reason, 18 key points that stand for the principal ventilation circuit have been selected, collecting the main ventilation parameters every month from 2008 to 2013, which are detailed below. Figure 1 displays an example of the points used to obtain the friction factors.

—Geometric features of the galleries: section, perimeter, length, roughness and any permanent obstacles in the ventilation circuit.

—Dry and wet temperatures: used to control and link airway roughness and surface climate conditions

—Air velocity: knowing the section, it is possible to calculate de airflow.

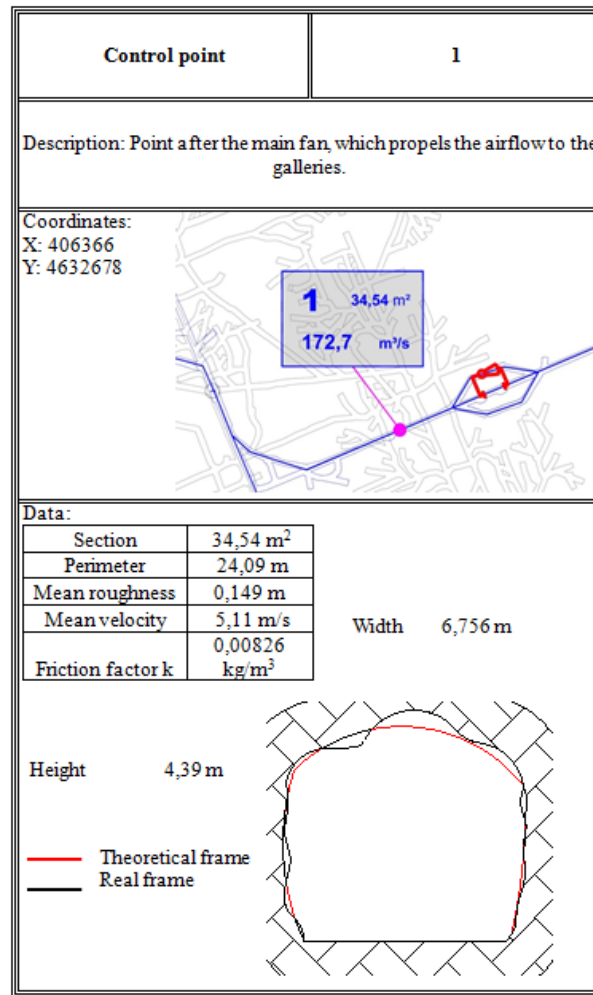


Fig. 1. Description of one of the control points.

Two important aspects in the process of calculating the friction factors have been taken into account in this paper, the Reynolds number and the hydraulic diameter. The first one is necessary to know the fluid rate and so use the proper equation and the second one to adapt the noncircular diameter of the galleries to the equations.

Once all the information detailed above has been collected, the friction factors have been calculated for each key point four times, corresponding the four seasons of the year, because airflow and temperatures suffer an important variation during the year, affecting the friction factor result. Finally, the mean friction for each point has been obtained.

### 3. RESULTS

Table 1 shows the mean parameters used to calculate the friction factors. They have been either measured in situ or calculated with the data collected from 2008 to 2013.

The values displayed in table 2 correspond to the mean friction factors per season and the general value per point, taking into account the four seasons values in each key point, as well as the standard deviation [19].

The current bibliography details the friction factor values for coal and metal mines. Tables 3 and 4 compare the results obtained in this paper with the published data among different types of airways. Despite the survey is focused on a potash mine, not on coal or metal mines, it is possible to get a rough idea of the reliability of the results.

**Table 1.** Parameters used to calculate the friction factor

Point	A, m <sup>2</sup>	Per, m	Dh, m	V, m/s	e, m	f
0	40.00	24.60	6.50	4.42	0.36300	0.01880
1	34.54	24.09	5.74	5.11	0.14900	0.01345
2	31.84	22.60	5.64	0.94	0.14390	0.01336
3	34.04	23.22	5.86	4.33	0.13260	0.01273
4	27.86	21.85	5.10	4.36	0.11000	0.01250
5	34.80	23.24	5.99	0.52	0.14170	0.01296
6	28.37	21.50	5.28	0.81	0.23330	0.01687
7	23.86	17.50	5.45	0.43	0.23750	0.01676
8	31.54	25.00	5.05	0.38	0.11910	0.01295
9	32.29	23.09	5.59	1.71	0.30000	0.01845
10	27.83	22.03	5.05	4.07	0.18240	0.01543
11	26.89	20.73	5.19	5.62	0.11440	0.01261
12	24.36	18.00	5.41	6.40	0.10000	0.01178
13	35.96	26.28	5.47	4.70	0.12000	0.01258
14	21.61	20.00	4.32	0.46	0.17480	0.01622
15	31.33	19.34	6.48	1.58	0.17480	0.01366
A	29.82	21.89	5.45	0.91	0.30000	0.01868
D	33.40	23.00	5.81	0.71	0.23750	0.01630

**Table 2.** Mean friction factor and standard deviation for each point

Point	Spring k, kg/m <sup>3</sup>	Summer k, kg/m <sup>3</sup>	Autumn k, kg/m <sup>3</sup>	Winter k, kg/m <sup>3</sup>	General value k, kg/m <sup>3</sup>	Standard deviation
0	0.01163	0.01134	0.01168	0.01184	0.01162	0.00021
1	0.00821	0.00801	0.00822	0.00838	0.00820	0.00015
2	0.00835	0.00848	0.00835	0.00853	0.00843	0.00009
3	0.00794	0.00778	0.00787	0.00802	0.00790	0.00010
4	0.00781	0.00796	0.00781	0.00796	0.00788	0.00009
5	0.00743	0.00701	0.00750	0.00739	0.00733	0.00022
6	0.00876	0.00872	0.00875	0.00933	0.00889	0.00029
7	0.00860	0.00856	0.00857	0.00856	0.00857	0.00002
8	0.00894	0.01014	0.00900	0.00940	0.00937	0.00055
9	0.00947	0.00787	0.00952	0.00900	0.00896	0.00077
10	0.00890	0.00890	0.00900	0.00893	0.00893	0.00005
11	0.00735	0.00729	0.00738	0.00732	0.00733	0.00004
12	0.00690	0.00686	0.00677	0.00677	0.00682	0.00007
13	0.00798	0.00855	0.00803	0.00821	0.00819	0.00026
14	0.00956	0.00956	0.00963	0.00956	0.00958	0.00003
15	0.00758	0.00694	0.00821	0.00759	0.00758	0.00052
A	0.01081	-	0.01207	0.01088	0.01125	0.00071
D	0.00956	-	0.00972	0.00960	0.00963	0.00009

**Table 3.** Comparison between published data and values from the paper

Airway type	Prosser and Wallace (2002)	McPherson (1993)	Hartman et al. (1997)	Paper values
Rectangular Airway–Clean Airway (Coal and soft rocks)	0.0075	0.0090	0.0080	0.0073
Rectangular Airway–Some Irregularities (Coal and soft rocks)	0.0087	0.0090	0.0091	0.0084
Metal Mine Drift	0.0088	0.0120	0.0269	0.0115
Metal Mine Ramp	0.0116	-	0.0297	0.0082

**Table 4.** Percentage difference between paper and bibliographic values

Airway type	Paper values	Difference, %		
		Prosser and Wallace (2002)	McPherson (1993)	Hartman et al. (1997)
Rectangular Airway–Clean Airway	0.0073	2.32	22.78	9.14
Rectangular Airway–Some Irregularities	0.0084	3.20	6.76	7.95
Potash Mine Drift	0.0115	23.68	4.08	133.30
Potash Mine Ramp	0.0082	40.95	-	260.87

### CONCLUSIONS

The characteristic friction factors in a potash mine using a room and pillar method have been determined. Despite each mine has its own characteristics, it has been achieved a framework for future studies related to mine ventilation in this type of exploitations.

The Chezy–Darcy and Atkinson equations have been employed to calculate the friction factor  $k$ , using the parameters measured in the control points. Roughness of the airways is due to, basically, the exploitation method and the nature of the de deposit, which has a certain deformable properties that define the shape of the tunnels.

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