## 6.4 A THEORETICAL MODEL TO CALCULATE GOAF RESISTANCE USING GOAF DRAINAGE DATA

### 6.4.1 THEORETICAL BACKGROUND

The goaf gas atmosphere is not only affected by the suction pressure and face-to-hole distance, but also air flow pathways. There may be multiple sources of seam gas emissions, but the air in the goaf mainly comes from the working face. After simplifying the ventilation air leakage pathways, a theoretical model to calculate goaf resistance has been proposed based on the goaf gas drainage data (suction pressure and air flow rate). Then the degree of goaf compaction and associated goaf permeability can be predicted as well.

The Hagen-Poiseuille’s equation, also known as the Poiseuille equation, is suitable for the calculation of incompressible laminar fluid, and the fluid viscosity is assumed to be not affected by the flow velocity (McPherson, 2009). The Poiseuille equation can be written in the standard fluid mechanics notation (Eq. 6.4), which directly describes the relationship of pressure drop and volumetric flow rate. It is used for pressure drop calculation under the conditions of given pipe size and fluid viscosity in engineering applications.

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|  |  | (6.4) |
|  |  | (6.5) |

Where, () is the fluid viscosity; () is the length of the pipe; () is the volumetric flow rate; () is the pipe diameter; () is the laminar flow resistance.

Kirchhoff’s first law states that the sum of all air entering a node is equal to the sum of air leaving that node (McPherson, 2009). This law explains that the mass flow through node j remains constant in the ventilation network (Eq. 6.6). In underground ventilation, if the air density change is small and can be ignored (Eq. 6.7), the input flow rate for node j is equal to the output flow rate.

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|  |  | (6.6) |
|  |  | (6.7) |

Where, is the mass flow; is the air density.

The equivalent resistance method is normally adopted in ventilation network analysis. There are usually two or more airflow pathways connected in series or parallel, and the resistance of different paths can be combined into one equivalent resistance. The schematics of ventilation airways in series and parallel are shown in Figure 6.9. In the laminar flow regime, the pressure drop and flow rate have a linear relationship, and the total pressure drop of the series airways is equal to the summation of the pressure drop in each branch (Eq. 6.11). Finally, the equivalent resistance (Eq. 6.12 or 6.13) of the series airways is obtained.

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|  |  | (6.8) |
|  |  | (6.9) |
|  |  | (6.10) |
|  |  | (6.11) |
|  |  | (6.12) |
|  |  | (6.13) |

As shown in Figure 6.9 (b), the total pressure drop is the same for airways in parallel. According to Kirchhoff’s laws, the total flow rate through the node is equal to the sum of each branches’ flow rate (Eq. 6.15), and the equivalent resistance of the parallel airways can be calculated (Eq. 6.16 or 6.17).

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|  |  | (6.14) |
|  |  | (6.15) |
|  |  | (6.16) |
|  |  | (6.17) |

图表, 图示

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*Figure 6.9 The combined resistances in series and parallel airways (McPherson, 2009)*

### 6.4.2 MODEL ASSUMPTIONS

In order to simplify the calculation of the theoretical resistance model, four assumptions are made here:

1.Air leakage can migrate from the working face to each goafhole, and the working face pressure is assumed as the barometrical pressure. Then the leaked air can flow autonomously from the working face to goafholes driven by the differential pressure.

2. The air flow into each goafhole is categorised as two types of pathways: (1) the air directly leaked from the face ventilation, without being affected by other goafholes and (2) the air migrated from the face and passed multiple goafholes that are closer to the face. A goafhole can only receive air passing from its nearest neighbour.

3. The air passing between neighbouring goafholes can only travel in one-direction from the face to deep goaf. In addition, the differential pressure between two neighbouring goafholes need to be positive to facilitate the migration of air.

4. The air flow resistance in the type (1) pathway is equal to the combined resistances of air flowing through the type (2) pathway originated from the face.

### 6.4.3 METHODOLOGY

According to the fundamental laws of fluid flow in the ventilation network and above assumptions, a series of equations were proposed to calculate the resistance of different air leakage pathways in the goaf. The resistance of each airflow branch in the goaf can be calculated after applying the field goaf gas drainage data (pressure difference and air flow rate) into the resistance calculation method. To explain the proposed method, an example of simplified ventilation network with two boreholes is shown in Figure 6.10, and each blue arrow describes one possible airflow pathway from the face to the boreholes. As shown in the figure, each goafhole can only receive leaked air from the face directly or the neighbouring borehole closer to the face (the one on its left in Figure 6.10).

The following parameters can be obtained from the raw goaf drainage data: and represent the air leakage flow rate from goafhole and ; ,, and represent the pressure loss of three airflow pathways, from the working face to , the working face to , and to , respectively.

Using these known parameters, ,, and represent the resistance of the three airflow pathways, from the working face to , the working face to , and to , respectively, can be calculated using the equations below (Eq. 6.18-Eq. 6.23). Besides, these equations can also be used to calculate ,, and , which refer to the air leakage flow rate of the three different paths, from the working face to , the working face to , and to , respectively. Therefore, using the six equations below, all six unknow parameters () can be solved simultaneously, given that are known from goaf drainage data.

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|  |  | (6.18) |
|  |  | (6.19) |
|  |  | (6.20) |
|  |  | (6.21) |
|  |  | (6.22) |
|  |  | (6.23) |

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*Figure 6.10 A schematic of the simplified goaf ventilation network (2 BHs case)*

When there are three boreholes working simultaneously (Figure 6.11), the first two boreholes, and , can be combined into an equivalent borehole to simplify the calculation. Using this equivalent assumption, the required parameters of the equivalent borehole can be obtained by Eq. 6.24-Eq. 6.28 based on the assumptions made in Section 6.4.2. All these parameters have the same units as the two boreholes case. Since are known parameters measured from each goafhole, all airway resistances (,, can be solved following the steps below.

(1) Calculate using Eq. 6.24 to Eq. 6.28.

(2) Apply parameters obtained from Step (1) to Eq. 6.18 to Eq. 6.23, and thus for three active boreholes, their airway resistances and air quantity (can be calculated following the two boreholes scenario.

(3) Once is solved, then can be solved using Eq. 6.30 and so as .

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|  |  | (6.24) |
|  |  | (6.25) |
|  |  | (6.26) |
|  |  | (6.27) |
|  |  | (6.28) |
|  |  | (6.29) |
|  |  | (6.30) |

If is negative, based on the assumption, this indicates there is no air flowing between and . Thus, is assumed to be infinity large in this condition, and is equal to . Besides, the other airway resistances (,, are solved by Eq. 6.18 to Eq. 6.23, same as the two boreholes scenario.

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*Figure 6.11 A schematic of the simplified goaf ventilation network (3 BHs case)* *(a) Base model (b) Equivalent borehole () model*

If there are *n* boreholes working simultaneously (*n*>3), the first (*n*-1) boreholes can be combined into a new equivalent borehole to simplify the calculation as shown in Figure 6.12 (a) and (b). The relevant parameters of the new equivalent borehole  can be calculated using Eq. 6.31-Eq. 6.35, and then follow the two boreholes case using Eq. 6.18-Eq. 6.23 to solve ,, and. If is negative, there is no air leakage between  and . Therefore, is assumed to be infinity large, and is equal to .

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|  |  | (6.31) |
|  |  | (6.32) |
|  |  | (6.33) |
|  |  | (6.34) |
|  |  | (6.35) |

Once and are determined, the same equivalent borehole assumption can be repeated by merging the first (*n*-2) boreholes into a new equivalent borehole (Figure 6.12 (c)), and then and can be calculated by repeating the previous steps. Thus, by back-propagating from to after applying equivalent borehole assumption and Eq. 6.18-Eq. 6.23 multiple times, for *n* active boreholes, their airway resistances can be calculated one by one. For a single borehole , represents the goaf resistance for air migrating from the working face to the borehole, which is the air leakage resistance in the type (1) pathway as introduced in Section 6.4.2.

**图形用户界面, 图表

描述已自动生成***Figure 6.12 A schematic of the simplified goaf ventilation network (n BHs case) (a) Base model (b) Equivalent borehole () model (c) Equivalent borehole () model*