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GASMAK2 Model for Longwall Gob Gas Emission

Qinghua Jin

Thesis submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Mining Engineering

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2002

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Abstract

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Qinghua Jin

This thesis discusses the development and improvement of an empirical model, – GASMAK2, that describes methane control requirements for the longwalling coal in gassy areas. This is not a theoretical model; it uses an empirically determined gas emission rate as an input. The computer program divides longwall panels into segments, keeps track of the face advance and generates emission rates and volumes for both the entire panel and for individual zones within the panel. This model is Windows-based, uses the full capabilities of the Windows environment to provide a user-friendly program, and can aid in the determination of the number, size and location of methane control techniques that are needed for gob gas control. It is an excellent approximation, and the use of this model in conjunction with a careful data collection program should clearly indicate what future methane controls are needed.

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List of Symbols

A	Gas content of coal sample dependent upon coal initial pressure
C	Concentration of the specific gas
D	Coefficient of diffusion
k	Permeability
t	Time after start of desorption
t_0	Time constant depend upon coal lump size
u	Gas velocity
u_x	Velocity of diffusion in the x direction
V_t	Volume of methane released from a coal sample per mass of coal sample
μ	Dynamic viscosity
$\partial p / \partial x$	Pressure gradient

Chapter 1 Introduction

With higher coal mining productivity and the trend towards mining deeper coal seams, emissions of methane from coal mines have increased significantly in modern coal mines. The ability to control methane in underground coal mines not only has a direct impact on mine safety and productivity, but it is also an economic issue. The mine operator needs to balance cost, efficiency, and safety at the same time. Coal mine gas has always been a major problem for miners. The gas emitted from coal seam and rock has always been regarded as a potential disaster for safe mine production ever since humans began to mine coal. Traditionally, methane control was performed using simply the ventilation system; however, this is more difficult or impossible to achieve nowadays. Additionally, methane released to the atmosphere is a major greenhouse gas contributing to global warming. In order to improve mine safety and to decrease downtime from methane in the mines, degasification systems to extract and/or capture much of the coalbed methane from coal seams before, during, or after mining are conducted. Methane drainage offers the added advantages of reducing ventilation costs, reducing development costs of the mine, reducing global warming threat, and allowing a waste product to be productively utilized. There are several kinds of gas drainage and capture technologies to control the gas in the working faces and roadways of mines. Gas recovery by gob wells is the most effective way to reduce gas emission and develop coalbed methane in longwall mines.

This thesis presents the characteristic of methane storage, flow, and control techniques. It also presents a Windows-based empirical model GASMAK2 for predicting longwall gob gas emissions. It can aid in the determination of methane control measures that needed for gob gas control.

Chapter 2 Literature Overview

Methane is one of the most common strata gases. It is generated during the formation of coal and is subsequently stored in the coal seams and other rock strata by pressure. The amount of methane stored in coal is controlled by the pressure of the coal seam and other rock strata, and by the degree of coalification. When gas pressure decreases as a result of mining activities, methane flows out of the coal and into the atmosphere. Methane is not toxic but it is a safety hazard because it is highly explosive in atmospheric concentrations of 5 to 15 percent. Methane explosions have resulted in the deaths of many thousands of miners. As a result, degasification of the coal to acceptable levels is paramount to a safe and successful mining operation. Historically, the mine ventilation system has been a primary mechanism for controlling methane concentration to required safe levels. Underground mines are ventilated with large quantities of air to dilute methane to safe levels and vent it to the atmosphere. Today many countries use methane drainage techniques to reduce methane levels, and to reduce gas disasters. Methane gas control is a key element in mining operations and it has greatly enhanced safe production of coal mines. To date, a number of different gas drainage methods and technologies suitable for different geological and mining conditions in different mines have been developed. In these cases, the ventilation systems are supplemented with methane gas drainage systems.

2.1 Methane Storage

Methane is retained within fractures, voids and pores in the coal in two distinct forms, generally referred as compressed gas (free gas) and adsorbed gas (gas adsorbed onto the internal coal surfaces). The surfaces of coal are the discontinuities within matrix structure. The gases

acting at the surfaces are unsaturated and mixed. When the coal is exposed to gases, the gas molecules will form bonds with the free surfaces. When the adsorptive bonding energy exceeds the short-distance repulsive force between gas molecules. The adsorbed molecules will become packed together as a monomolecular layer on the surface. In similar fashion, additional molecular layers may form at higher pressures. Different gases adsorb onto coal surface at different bonding strengths. Coal contains a very large number of small pores and a correspondingly high internal surface area. Significant quantities of methane may be adsorbed onto coal's surface, and typically accounts for 98% of the gas within a coal seam. The amount of gas in coalbed depends on temperature, pressure, degree of fracturing, rank, and permeability of the coal and surrounding strata. When the strata is pierced by boreholes or mined openings, the gas pressure gradient created induces migration of the methane towards those openings.

2.2 Methane Flow

Coal has an extensive natural fracture system called cleats (Kruger D., 1990,). There are two orthogonal sets of cleats, butt cleats and face cleats (shown as Figure 1). The distance and development between cleats can vary greatly between coal seams. This cleat system controls the permeable flow of methane once it has diffused through the coal.

Figure 1: Illustration of the Coal Cleat System (ICF Resource, 1990)

Flow within the cleat system is described by Darcy's dynamic flow equations as free gas moving as a result of a pressure gradient. Darcy proposed this theory about gas flow in the fractures of permeable media as shown in Equation 2.1 in 1856 (McPherson, M. J., 1999).

$$u = \frac{k}{\mu} \frac{\partial p}{\partial x} \quad \text{m/s} \quad (2.1)$$

Where u = gas velocity (m/s)

k = permeability (m^2)

μ = dynamic viscosity (Ns/m^2)

$\partial p / \partial x$ = pressure gradient (Pa/m)

Darcy's Law relates the flow rate in a reservoir to the pressure drop across the reservoir using a proportionally constant (i.e., permeability) and describes gas transport through the fracture system in the coal where the driving force is the pressure gradient.

Diffusion flow occurs whenever a difference in concentration of molecules of a given gas occurs. The diffusivity property is represented by the coefficient of diffusion. The flux of gas transported in this mode follows the Fick's law of diffusion described by Equation 2.2 (McPherson, M. J., 1999):

$$u_x = -D \frac{\partial c}{\partial x} \quad \text{m/s} \quad (2.2)$$

Where u_x = velocity of diffusion in the x direction (m/s)

D = coefficient of diffusion (m^2/s but most often quoted in cm^2/s)

C = concentration of the specific gas (m^3/m^3 of coal)

This law describes diffusion along the concentration gradient. The negative sign in the equation is necessary since movement occurs in the direction of decreasing concentration.

A high gas content coal does not necessarily imply a high gas flow. The ability of coal to transport the gas is measured by the properties of permeability and diffusivity. A number of references indicate that the movement of gas in coal is caused by Darcy (laminar) flow down a pressure gradient or diffusion along a concentration gradient. The literature provides no clear answers as to which type of behavior is taking place or which type of transport governs the rate of gas production. Controversy has existed and this might be because of the wide variation of properties that existed in coal structure. Current thinking is that within the coal matrix, diffusion and laminar flow occurs while, in the cleats and fractures, Darcy (laminar) flow dominates (Figure 2). Most investigations agree that diffusion flow is the controlling factor governs the rate of degassing coals of high permeability while Darcy flow in the fracture network is the dominant effect in high diffusivity coals.

Figure 2: The Transport Methane Gas in Coal (ICF Resources, 1990)

In an undisturbed state, equilibrium exists between free gas and adsorbed gas in the pores and fracture networks of coal. If, however, the coal seam is intersected by a borehole, or disturbed by mining, then a gas pressure gradient that is created will result in flow through natural or stress-induced fractures. The reduced gas pressure in the pores will promote desorption.

Permeability is a measure of the ability of gases to flow through coal seams and surrounding rocks. Coal permeability depends upon the cleat structure, fractures, and the nature of their inter-connections. Strata movement, relaxation and compaction due to mining will change the permeability, which obviously means that disturbances by mining can decrease or increase the permeability. Because coal permeability is highly stress-dependent, it is a difficult parameter to numerically characterize in mines.

After desorbing from the coal surface, the movement of methane through the coal matrix is controlled by the concentration gradient of methane molecules (diffusion). In diffusions,

molecules move from a zone of higher concentration to a zone of lower concentration. The movement of methane by diffusion occurs until the molecule intersects an open pathway or fracture in the coal, whereupon Darcy flow dominates.

2.3 Methane Control Techniques

With higher mining productivity and the trend towards mining deeper coal seams, emissions of methane from coal mines have increased significantly in modern coal mines. And, as previously mentioned, methane is a serious safety threat in coal mines.

Traditionally, the main technique used for controlling methane concentration has been ventilation. However, it is increasingly difficult to achieve economically today because it is not possible to move enough air to adequately dilute the increased methane emission. In order to improve mine safety and decrease downtime as a result of high concentration of methane in the mines, methane control systems to extract or capture much of the coalbed methane are needed. Particularly in gassy mines, the ventilation have to be supplemented with a drainage or capture system. Drainage systems reduce methane concentrations to acceptable levels in the working areas by draining the gas before, during, or after mining, depending on mining needs and mine design. There are three basic families of methane control techniques:

- Predrainage,
- Active Drainage, and
- Postdraiange.

In many cases, a combination of the above three drainage techniques are used.

Methane drainage methods used in the U.S. mainly include vertical wells, gob wells, horizontal boreholes, and cross-measure boreholes. No matter what methane control techniques

the operator uses, the primary purpose is the same: remove enough gas from the mine, so that ventilation system can dilute the remaining gas that will be emitted into the mine to acceptable levels.

Figure 3 is from Guidebook on Coalbed Methane Drainage for Underground Coal Mines (Mutmanský, J. M., 1999), it gives us a general view of predrainage and postdrainage methane control techniques.

Figure 3: The General View of Coalbed Methane Drainage for Underground Coal Mines

2.3.1 Predrainage

Predrainage techniques are used for draining gas from the coal seam and the adjacent strata before mining operations begin. (Creedy, D. P. et al., 1997)

Stimulated vertical wells are the optimal predrainage techniques used in the United States. Vertical wells are drilled through a coal seam or seams and used to predrain the methane several years in advance of mining. They typically require hydraulic stimulation to fracture the coal seam. They can remove from 50 to 90 percent of gas content from the coal seam,. This is high concentration gas that may be sold commercially. One advantage of this method over the other techniques is that they can be applied to multiple coal seams simultaneously.

2.3.2 Active Drainage

Active drainage techniques are employed for capturing gas from the coal seam being mined and the adjacent strata during the active mining operations.

Horizontal holes are the most common active drainage technique used in the United States. They are drilled from the mine workings into unmined areas of coal seam. They drain methane from the coal seam prior to mining so that the methane content may be reduced before mining and limit the flow of methane into the mining section. Because methane drainage occurs only from the mined coal seam and the period of drainage is relatively short, the recovery efficiency of this technique is low. In most cases, only 30% to 50% of the methane contained in the coal seam being mined may be drained using this technique.

2.3.3 Postdrainage

Postdrainage techniques are the most important method used in longwall coal mines today. The gas volume drained by this method accounts for 80 to 85 percent of the total volume produced at the mine. It is common knowledge in the mining industry that gas emitted from

surrounding strata can release high volumes after mining activities pass through, far exceed the gas emitted from the actively mined coal seam itself.

Vertical gob wells are boreholes that extract methane from the gob areas of a mine. (A gob area is where all the coal has been removed; overlying strata has collapsed, fractured, and subsided.) Gob wells differ from pre-mining vertical wells in that they are operated only after mining has been completed in the well location and fractures the strata around the well bore. The methane emitted from the fractured strata then flows into the well and up to the surface, frequently with the assistance of vacuum pumps. The number of gob wells on a longwall panel is controlled by mining rates and the gas content of the caved strata. When this technique is used with good controls, methane extracted from gob wells can be put in a pipeline. The principal disadvantage is the need of acquisition of surface rights and surface environmental planning restrictions.

Cross-measure boreholes, a technique common in European countries, are drilled at an angle above, and sometimes below the strata being mined from existing mine entries. The boreholes are strategically pre-placed in areas to be mined out with the goal of draining the overlying or underlying strata and exhausting gas from the gob area. The angle at which the holes are drilled is a function of the height and width of the geologic zone to be drained, the panel width, and the location of the entry from which the holes are to be drilled. Anywhere from 35% to 75% of the total gas released in an underground district can be captured at purities ranging from 35% to 70%. Higher purity gas is generally not available. However, there are markets for low-quality gas in Europe.

The cross-measure system for coalbed methane drainage has been most successful in Eastern Europe and Asia, while the general ease of using vertical gob wells in the U.S. make the

use of cross-measure boreholes uneconomic. Gob wells are the most effective method of reducing methane content in rapidly moving longwall faces. Cross-measure systems may become attractive in the U.S. only in areas where surface access is difficult.

Although coalbed methane may be controlled by the above three drainage techniques, the literature overview indicates the postdrainage approach is likely to be the most common technique all over the world because of the higher levels of emissions from surrounding strata. For this reason, this thesis focuses on gob wells.

2.4 Previous Methane Prediction Models

The development of coalbed methane drainage projects has fostered modeling efforts all over the world (Curl, S. J., 1978). A review of currently available models and related identified models and laboratory experiments used to predict methane emission in underground coal mines. There are different types of models, and adapting these models for all situations posed several problems. The worst problem is that site specific data would be needed for every region. The few global emissions models that exist are reasonable, but are hampered by lack of practical input information to use theoretical approaches accurately. Some data are not even available for some countries.

The methane prediction models can be subdivided into the categories of numerical, empirical, and statistical models depending on the methods used in their calculations. Of these models, the numerical models are the most popular. Numerical models are the most general, but they use sophisticated boundary conditions and theoretical inputs that are not well understood, and this leads to a wide range of methane production assessments. Methane emission models using statistical approach are rarely found in literature. The reason for this may be that most

model developers have made their statistical approach fall within the category of an empirical approach.

2.4.1 Empirical models

The empirically based models are the simplest models among the three categories. Empirical models are based on simple mathematical descriptions of observable physical phenomena. They are very fast, only simple input is needed and the formulas are very easy to apply. Although the empirical models are relatively simple, requiring few input parameters, they lack the theoretical precision required for detailed predictions. The empirical models are limited by observations used in their development. Care must be taken to ensure that the assumptions and accuracy support the model development. Nearly all the empirical methane models are formed by fitting a simple function to a set of data, including this GASMAK2 model of my thesis work. These models are relatively easy to develop, but their predictive power is restricted by the limitations of the input data set.

2.4.2 Numerical model

Many researchers have developed numerical models for predicting methane production from coal seams in the past for two main purposes: to enhance understanding and to enhance prediction accuracy. The domain size of these numerical models range from laboratory scale to single-well, full-field models. Nearly each numerical model has its own specialized uses, but few are universally applicable. The numerical models are solved using numerical techniques such as finite element methods. The physical relationships in these numerical models are represented by functions, differential equations, and inequalities (King, G. R., & Ertekin, T. M.,

1989). For a numerical model to be practically useful one, the user needs a high degree of knowledge about the domain of application. Current knowledge is not adequate for theoretical approaches or we do not understand how the basic parameters change with time, distance, or with the influence of mining. Also, numerical models are limited by coding difficulties because we can not describe the theory precisely in computer language. There can be a significant range of uncertainty in the value of the parameters input to the numerical model.

2.4.3 Statistical model

It is common to find statistical models for estimating methane resources in the petroleum industry; but it is rare in the mining industry. During the literature overview, only one statistical model for methane resource estimating was found from internet. It is reported (Coal mine methane resources estimation and reserve evaluation) that this model used frequency distributions of the parameters and quantifying the risk associated with the resource estimate and therefore increases the confidence level of the estimate. This type of analysis can be facilitated through random sampling of distributions, therefore, allowing the probability of occurrence of resource volumes to be determined. The investigator estimated coal mine methane resource based on single value or the average of measurements of important parameters, for example, gas content, coal density and coal thickness. Figure 4 shows a forecast distribution for the gas in place of a coal seam using the statistical model (Pilcher, R. C., Collings R. C., & Marshall, J. S., 2000).

Figure 4: Gas in-place forecast showing the probability of occurrence of each class of occurrence

This figure shows that there is an 80.13% probability that a 160-acre (64.75 hectares) tract will have between 1 and 6 million cubic feet. It seems there is not practical use for the statistical model because it just offer the user the probability.

It is worth mentioning a very sophisticated model-“Floorgas and Roofgas Geomechanical and Gas Release Model”-developed by Lunagas Pty Limited, Newcastle, Australia. It has been commercialized and operates on a PC Windows-based platform. This model relies heavily on geological factors, experience, and history matching. It might be the most sophisticated model in the world currently. Nevertheless, a substantial quantity of geomechanical and lithological input data are required to run this model. The reasonably accurate prediction results are sound, provided sufficient geological, mining, and gas data are made available. But in many situations, the user could not have all the information required about these input data, and it is difficult for us to use this model then. Although this model uses theory heavily, its reliance upon historical data still places it firmly in the empirical category.

Figure 5 shows the development of a particular gas emission decline curve (gas emission decay with time) for a specific location (<http://members.ozemail.com.au/~lunagas/>).

Figure 5: Gas Emission Decline Curve (Gob Area) for “Floorgas and Roofgas Geomechanical and Gas Release Model”

Figure 6: Gas Emission Decline Curve (During and Post Extraction) for “Floorgas and Roofgas Geomechanical and Gas Release Model”

Empirical models lack the theoretical base required for accurate prediction, but numerical models lack the availability of accurate input data. With current knowledge, an empirical approach is the most useful. The GASMAK2 model is empirical.

Chapter 3 The GASMAK Model: Original Program Overview

For longwall coal mine operation, the first thing that must be determined is what gas volume and what emission rates longwall mining operation will produce. An empirical model, GASMAK, was developed by Lloyd M. English (English L.M., 1997) that could forecast gas inflow rates and volumes based upon basic local data and historical information from similar sites.

3.1 Overview of the GASMAK Model

GASMAK model was initially presented in the Ph.D. dissertation of English (1997).

3.1.1 Domain of GASMAK2 Model

GASMAK model is developed specially for gob gas control. Studies indicate that the methane produced by the gob areas can exceed 80% of the total methane produced in a mine. There are 84 mines (of more than 400 mines total at present) in the United States that are classified as gassy mines. Among the 84 gassy mines, only 33 have gas drainage systems and the others depend solely on ventilation systems to control methane. A summary of gas drainage methods used in the United States is shown in Table 1. According to this table, 31 of the 33 mines with gas drainage systems have adopted gob well drainage technology, accounting for nearly 94% of the total. Seventeen of these mines simultaneously use other methane control techniques as well. Gob well drainage technique is the most common method in the U.S. coal industry. Most mine operators that use gob wells can make reasonable estimates of the effectiveness of their gob wells. Gas recovery by gob wells may be the most promising way to

reduce gas emissions and to develop coalbed methane as a commercial resource safely. This provides the impetus for using a model such as GASMAK.

Table 1 Summary of Gas Drainage Methods in the United States

Number of mines	Drainage methods
1	Underground gas drainage
1	Underground gob gas drainage
14	Gas drainage by surface gob wells
5	Gob well drainage and underground gas drainage
12	Gob well, underground gas drainage, and pre-drainage using surface vertical wells

3.1.2 Empirical Approach

Since the beginning of the coalbed methane industry, operators have relied greatly on technology from the petroleum industries to evaluate and develop coalbed methane properties. Much of this conventional oil and gas technology applies to coalbed methane operations, but often it must be modified. In some cases, coalbed methane operations require entirely different techniques. Currently, the knowledge is not detailed adequately for theoretical approaches.

The GASMAK model is empirical. In order to estimate methane generation in gob areas of the longwall panel, English identified the key variables that affect methane generation and developed an empirical model of methane generation based on these variables. The key parameters of this model are the methane emission rate as a function of time. The GASMAK model uses empirically determined gas emission rates as an input rather than depending on reservoir and rock mechanical theories to calculate emission rates. The model is coded in FORTRAN language.

3.1.3 Essential Assumptions

Two following foundational assumptions are used in the development of his GASMAK model:

1. *In specific, local geographic regions, uniform increments of gob produce methane in a relatively consistent manner.*
2. *Although carbonaceous materials will contain varying amounts of methane, they produce that methane by similar processes, yielding desorption curves that vary in magnitude but not in form. (English, L. M. 1997)*

3.1.3.1 Uniformity of Increments of Advance

GASMAK model divides a longwall panel into equal length segments shown as Figure 7.

Figure 7: Segments Divided by GASMAK Model for a Long Wall Panel (English, 1999)

The first basic assumption is that, within a specific geographic region, each uniform increments of mining advance will create equal volume of gob, and for this volume of gob an

equivalent quantity of methane will be produced. Many studies show that this assumption is reasonable, because coalbeds usually are fairly continuous and their gas contents are uniform and predictable. This uniformity of coal thickness and gas content makes coalbed methane prospects fairly easy to evaluate. The same logic applies to carbonaceous shales and reservoir rocks. Also, even though specific strata thicknesses and ratios may change between core holes, if the thickness is adequate, the relative mix will not change significantly.

3.1.3.2 Consistency of Desorption Characteristic

The surfaces in coal represent discontinuities in the matrix structure. The gases acting at the surface are unsaturated and mixed. When the coal is exposed to certain gases, the gas molecules will form bonds with it and become adsorbed onto these surfaces. Gases adsorbed to coal are released when pressure is reduced due to increasing kinetic energy; this is the process of desorption.

Current thinking for methane and other adsorbed gases is that for a local geographic region, the coal desorption characteristic is consistent. The difficulties encountered in the derivation and general applicability of analytical desorption equations led Airey (Airey, E. M., 1968) to propose an empirical relationship:

The rate of release of methane was measured, and the volume V_t discharged in a time t conformed to the empirical equation (Airey model):

$$V_t = A(1 - e^{-(t/t_0)^{1/3}}) \quad (3.1)$$

Where:

V_t = (Volume of methane released from a coal sample)/(mass of coal sample), ft³/ton

A = Gas content of coal sample dependent upon coal initial pressure, ft³/ton

t_0 = Time constant depend upon coal lump size, hr

t = Time after start of desorption. hr

Airey's theory is a development of earlier work in which an empirical equation was proposed to describe the emission of gas from broken coal. The concept of time in Airey's theory enables, for example, emissions to be expressed as a function of advance rate. This empirical relationship has been verified to be compatible with subsequent testing in many coals of different quality (Airey, E. M, 1968). The Airey curve is the foundation of the development of GASMAK model.

Figure 8 shows the adsorption curve for a specific coal with an assumed initial gas content of 150 cu ft/st based on Airey model.

Figure 8: Standard Airey Curve

Often, researchers base models on fundamental principles. The fundamental principles must be well defined to be successful in model performance. In particular, we must ensure that the assumptions and the accuracy of available data support the calculations. A review of the published literature data strongly supports the reasonability of the basic assumptions that

desorption characteristics of various carbonaceous materials behave in similar form (Curl, S. J. 1978).

The two assumptions (uniformity of increments of advance, and consistency of desorption characteristic) form a strong basis for the development of this model using empirical methods.

3.1.4 GASMAK Model Operation

The GASMAK model is written in Fortran and operated in a DOS environment. The input required include panel dimensions, mining rate, average depth of cover, the segment size to be used to divide the panel, and the size and location of the emission zones of interest. After preparing the text input file, the model can perform the following steps:

- Divide the panel into segments and different zones;
- Track the mine face advance;
- Determine the time each segment is undermined;
- Interpolate the empirical input curve, calculating the emission rate for each segment at each point in curve and each point in time;
- Calculate the current panel emission rate from the accumulated rates for all undermined segments at given time i and,
- Report the panel gas emission rate and emitted gas volume for all undermined segments from time zero to project lifetime.

Based on the assumptions that uniform increments perform in a similar fashion while the gas desorbs from the gob, the total rate of methane emissions from a longwall panel at any time is the sum of the emission rates for all of the undermined increments belonging to that panel at

that time; unmined segments are sent directly to the summation line with gas emission rates and emission volume values of zero. Since this model depends on an empirically obtained curve, necessary measurements need to be made at the mining operation of interest. The GASMAK model determines the emission rate using linear interpolation performed on data points input for the emission curve. Linear interpolation is used for predicting the emission rate changes over periods of time, assuming that the rate of change consistently follows the empirically determined Airey curve.

One advantage of the GASMAK model is that it not only forecasts the total emission rate from an individual panel, but it also divides a panel into separate zones (refer to Figure 7). Which can provide estimates of emissions that must be controlled by individual gob wells (or other methane control techniques such as cross measure systems). This model can be a substantial aid to designing efficient and economic methane control systems.

As it was expected, GASMAK model is sensitive to the input data. Gob gas emissions tend to be consistent in specific mining operations and regions, because of the site-specific characteristics (data points being input for emission curve) are required as model input. This methane inflow model can forecast methane flows in the gob area once the empirical data can be obtained in the field. It is an aid to the mine operator for ventilation and methane control planning.

3.2 GASMAK Improvements Needed

The GASMAK model was developed using Fortran. Fortran is one of the oldest programming languages in use. The Fortran language suffers from several disadvantages when compared to other computer languages. Despite its disadvantages, its large user base among

scientists and engineers has maintained its popularity through the years. The most important disadvantages of Fortran language are:

- Memory can not be dynamically allocated; to run a larger problem one needs to recompile.
- There are no structures or linked lists (no pointers); one can implement them only in obscure ways.
- There is no low level access to I/O primitives.
- String manipulation is not straightforward.

Because of these disadvantages, there are some restrictions when using GASMAK model. For example, Project ID has a maximum of 65 spaces; segment numbers can not exceed 600, etc. The present GASMAK model can produce an output data table but it must be loaded into spreadsheet software for visualization. While operating this GASMAK model, the user must prepare an input table in the meticulous DOS format for the GASMAK model to read in advance. The most frustrating aspect of the GASMAK model is that, for a new GASMAK user, it is not modern standards of user-friendly uses.

The Windows-based GASMAK2 model was developed specifically to enhance user friendliness. Users can take the advantage of using an intuitive graphic user interface to increase their modeling efficiency. The interface has a consistent look and feel throughout the program, which enables users to navigate easily.

Chapter 4 GASMAK2 Model

Consider the following situation: An experienced user sits in front of a computer, attempting to complete a familiar task using an unfamiliar application. For each step in the process, the user first reads some instructions from the manual open at his/her side and then turns to the computer to actually accomplish the actions about which they have just read. What are the cognitive processes involved in this situation? How should the interface be designed so as to minimize the difficulty of the task? The task is easier when the interface matches the familiar Microsoft Office graphical user interface (GUI). There is no correct "answer" to be sought on what each application interface should look like, and there is no one interface that will be ideal for everyone. This interface will help as many users as possible to get the most out of the program.

The GASMAK2 model is Windows-based and uses the full capabilities of the Windows environment to provide a user-friendly program to the users.

4.1 Changes in This Model

The Windows-based model is easier to use because of the graphical user interface. One of the objectives of the GASMAK2 model is to develop a Windows-based empirical model of methane emission rate as a function of time using new programming language. The intuitive design helps users to focus their attention on the results, not on how to get them, and gives users a positive work experience and enhances productivity.

The GASMAK2 was developed using Microsoft Visual Basic 6 (VB). There are a large number of reasons for the development of this GASMAK2 model using Visual Basic (refer to

section 4.3). VB is a productive tool for creating high performance applications, gives a complete windows application development system in one package, permits writing, editing, and testing Windows applications, and provides user-friendly interfaces for input and output. In addition, VB includes tools for writing and compiling help files (refer to help menu of GASMAK2 model).

4.2 Approach

The aim of developing an empirical model is to exhibit the same behavior as the system that is being modeled.

Examining the second word in “empirical model”, what is a model? Neelamkavil states that “*a model is a simplified representation of a system (or process or theory) intend to enhance our ability to understand, predict, and possibly control the behavior of the system.*” (Neelamkavil, 1987). Assume that someone wants to build something – it is useful to know whether the plans are realistic and will succeed before actually proceeding with construction. A road bridge, for example, is very expensive to build, and if it does not perform to specification, may even result in a disaster. What is needed is a simplified model that can be used to test for performance. The model of course is simpler than the actual bridge, as the real artifact is a very complex thing. If the bridge were truly, perfectly modeled, the model would have to account for its many molecules, or even atoms; the model complexity would become unmanageable.

Now examining the first word in “empirical model”, the word empirical means “originating in or based on observation or experience” (WWWebster Dictionary). Empirical models are based on observation and experiment. If no relevant theory is available (or useable) to incorporate into the model, experiments and observations of the real world are made and

incorporated into the model itself, along with a logical approach for usage. In practice, the modeler will usually have some preconceived ideas about the system which may be used as an initial basis for the model.

The choice of the descriptor "empirical" reflects the fact that GASMAK2 model is rooted in observation and experiment, and accordingly approaches system development from a very different perspective than that associated with traditional numerical or theoretical models. As with all reservoir simulations, certain data must be available and some assumptions must be made to generate a forecast. In this GASMAK2 model, data points that contribute to understanding the methane production rates are used for interpolating emission curves that define the methane emission functions of the gobs that need to be measured or estimated.

4.3 GASMAK2 Model Development

Empirical models are based on observation, and on the dependability of those observations. Empirical models have both practical and technical aspects. The practical aspects are concerned with the construction of models that closely correlate with one's experience and that are always open to interaction and revision. The technical aspects are concerned with the logical development of a method for using the data as a foundation for computing.

4.3.1 GASMAK2 Modeling Flow

A guiding principle for the GASMAK2 model development was Airey's equation and the original GASMAK empirical model. Figure 9 is the flow of GASMAK2 empirical modeling development. There are two foundational assumptions used in the development of the GASMAK model, i.e., uniformity of increments of advance, and consistency of desorption

characteristic. (Refer to the chapter 3). From the flow of GASMAK2 empirical modeling development, one can see that the GASMAK2 model is based on a very simple and straightforward formula, the E. M. Airey equation. The advantage of this approach is that it is very fast, only simple input is needed, and the formula is very easy to apply.

Figure 9: The Flow of GASMAK2 Empirical Modeling Development

4.3.2 GASMAK2 Modeling Implementation and Methods

The GASMAK2 model was written in Microsoft Visual Basic 6, a visual programming language which provided the user interface design component necessary for our approach. Visual Basic provides most of the flexibility and discipline of other structured languages, such as PASCAL, and C, but allows the rapid development and prototyping of visual control elements. It is these visual control elements which are essential to providing non-computer expert access to GASMAK2. Figure 10 is the implementation diagram of GASMAK2 Model development. The main features of GASMAK2 development are input database, help system, and automation.

Figure 10: Implementation Diagram of GASMAK2 Model Development

4.3.2.1 GASMAK2 Model Input Database

The model input database is an extremely flexible and powerful tool for modifying model inputs. The GASMAK2 model can be run with the default settings by simply clicking the “OK” button on the appropriate dialog box. Alternatively, the properties of the model may be explored

by varying model inputs. This is done in GASMAK2 by editing input values, and using action buttons on the model dialog form itself, or by modifying the model input database.

Because GASMAK2 includes many potential input values, it is most practical to have two levels of input entry. The most commonly modified inputs and initial conditions for a sub-model are accessible on the model dialog itself. These inputs are commonly the driving variables of the model. All other inputs (data points being input for emission curve and gob well information, etc.) may also be accessed by entering the model input database. Changes made on the form are only active until the form is closed. Input changes must be made in the model input database, using the File-exit and save changes option, on completion to save the changes. In situations where an input occurs in both the model database and on a model dialog form, the value outlined on the form takes precedence when the model is run.

Traditionally model input files for GASMAK have been manipulated as complex ASCII files and required a separate ASCII file text editor. This is the technique used by the original GASMAK model. There are a number of problems with this approach. These include starting with a separate text editor program within the modeling environment, the discontinuity of user interface that this represents, and the complex formatting and abbreviations generally used in these files. To avoid these problems and to meet the specifications on ease of use, GASMAK2, employs an input database editor in a spreadsheet format which is consistent with the program, and a graph forms-based user interface for the rest of the model. This spreadsheet-like mode of operation will be familiar to anyone who has used a modern Excel such as Microsoft database program Access or Quattro Pro. The GASMAK2 input database editor is called from the model dialog menu and appears as an integral part of the modeling environment itself. The parameter database editor has facilities to cut, copy and paste information from other applications using the

Windows clipboard, and to search for text entries and values within the parameter database. It is also possible to print out either selected areas of the database or the entire database to any printer supported by Windows.

Data Access Objects (DAO) is a mature technology, with the bugs worked out. DAO gives complete control over the entry of data. DAO can be used to make changes to the tables that are immediate and do not need to refresh access records. A new recordset object is automatically added to the recordsets collection when user opens the recordset, and it is automatically removed when user closes it.

4.3.2.2 GASMAK2 Model Help System

In order to meet the criteria of accessibility and open documentation, GASMAK2 uses the Microsoft Help Workshop to create a help file. This help file has been created using Microsoft Word which to create Rich Text Files (RTF) containing the textual information, inserting graphics and adding header/footer entries that allow hyper-help functionality. The help workshop then compiles this RTF into a help file format that is compatible with the help file manager (winhelp.exe) and display system built into Windows operation systems.

The advantage of using a word processor and secondary workshop combination in this manner is that other scientists may contribute to the content of the help file without the need for any specialist programming skills. Also the word-processed help file may be used with little or no modification to form the basis of a printed manual or hardcopy documentation of the modeling system.

The initial task in constructing the help file in GASMAK2 was to gather information for the help topics; the second task was to develop a plan for the help system, which included i)

defining the likely audience of the material, ii) planning the content of the help system, iii) planning the structure of help topics, iv) determining the topic file structure, and v) designing the individual help topics. These processes are summarized diagrammatically in Figure 11.

Figure 11: Workflow Diagram for the Construction of Onboard Help System Contained Within GASMAK2 Model

The help file is available in GASMAK2 at all times from the help menu on the main user interface window and it will be discussed in section 4.3.4.2 in more detail.

4.3.2.3 VBA Automation (Automated Output)

Visual Basic for Application (VBA) in Microsoft Excel allows programming complex tasks within an application. It was first used to automate repetitive tasks and served to order the computer to do tasks that users usually did. Each iteration of Windows has contained a corresponding improvement in the techniques used for transferring data among its applications. Today's leading technique is called Automation (Jacobson, R., 1999). The GASMAK2 model can automatically generate the spreadsheet for output, but the resulting Excel output spreadsheet is very large (see Appendix A). Since most users will be analytical and visually inclined, charts and graphs can be used to explain complicated concepts, and to simplify the information conveyed. It is a great advantage to build in charts and graphs to visualize output information. Although most Excel users can create and format simple charts, personally figured charts and graphs ensure a level of conformity. Because VBA can do this more rapidly and more efficiently than the best user, the GASMAK2 contains workbooks to complete tasks that even well trained users could not perform within normal deadlines. Most of the functions needed to organize and analyze data are pre-programmed in Excel, so some common writing and spelling errors that occur during the programming are avoided.

To develop a good VBA program, the programmer must thoroughly master the functions and functionalities of Excel, understand the inner workings of Excel, work with the applications that support automation, listen to the user who has the knowledge of the data and understand what the user needs. At this point, the author is both the experienced user and the programmer. With the guidance of the creator of the original GASMAK model, normal programming never constitutes more than 25% of the work; the other 75% consists of understanding the needs of the user and designing the workbook within which the programming will be developed.

Microsoft Access is the bestselling stand-alone relational database program for Windows offering both power and ease of use. The recordset object is the primary object used to manipulate data in Access databases.

4.3.3 Calculation overview

The following page outlines a basic calculating block diagram of GASMAK2 model for longwall gob gas emissions. The major elements of the calculation in this model are shown in Figure 12. The description of the elements in the model is provided below.

<u>Model Element</u>	<u>Comments</u>
1	This section calculates the number of segments in the panel; the first segment is larger than the rest because emissions do not start until the first major fall occurs. It also calculates the face location – the distance from panel start-up to the end of segment i at which this segment starts emissions.
2	This section identifies those segments with emissions that go to a different zone when the face undercuts the next well, and computes the distance between start-up and well 1, the distance between wells, and the distance from the last well to the panel end.
3	Determines if the segment precedes the first well.
4	Determines if the segment is beyond the last well.
5	The segment containing the last well and all segments that follow are assigned to the last well.

Figure 12: Flow Sheet of GASMAK2 Model

- 6 This section calculates the distance W in advance of wells in which segments are influenced by the new well coming on line (i.e., the influence zone will change). W is always 0 for well 1. Assigns zones of influence for segments lying between wells 1 and n , some of the segments do not change zones, while the other segments change zones based on the data of segment “captured” by each well as it comes into production.
- 7 Identifies all of the segments up to and including the one that contains the first well, these will never change zones and permanently assigned to Zone 1.
- 8 Identifies those segments at the start of the panel that do not disturb overlying material to the maximum height. Calculate the number of segments in start-up region (i.e., number of segments until the full height of Gob development is reached).
- 9 Calculates the desorption index for each segment by taking the ratio of each cross-sectional area to that of the cross-sectional area of a uniform segment of advance. All segments beyond the start-up zone have an index of 1.
- 10 The times and face location are initialized, and the gas emission portion of the program is started. All time and gas variables are set to zero to start calculations, as is the face location. This section starts the time-controlled part of the program.

11	If project time has expired, terminates calculation and produces output.
12	Determines if the entire panel has been extracted.
13	Increments face location if the face has not reached panel end.
14	Calculates gas emission values without incrementing face if the entire panel has been extracted.
15	This section calculates the panel and zone gas values and generates a large quantity of output in Microsoft Excel format.
-

4.3.4 Components of the User Interface

In recent years, the design of user interfaces has been one of the key element for the development of any software system. Frequently, software projects have been devoting more to the design of the interface than the underlying application code. This is not just a function of a competitive market, it indicates that users are demanding more sophisticated software interfaces and the ability to use complex software easily.

The work of interface development for this GASMAK2 model was more than 80 percent of the total work of software development. The key approach in the design of GASMAK2 model interface is to provide a visual communication tool for the user. The interfaces are arranged in consistent way, are comfortable to use, and also provide a beneficial (e.g., assisting in a user's task) environment. In keeping with the standard Windows environment it is possible to use the mouse to select model dialog controls or to use the tab key to move from control to control on the form and the space bar to toggle between values.

The user interfaces are described at the following sections.

4.3.4.1 Password Interface

Password interface (shown as Figure 13) is for managing user access to this program. As a security precaution, a password is required to enter this GASMAK2 Model. If the password is unacceptable, the program exits. If the password is acceptable, the GASMAK2 model runs.

Figure 13: Password Interface of GASMAK2 Model

4.3.4.2 User Main Interface

Once started the GASMAK2 model automatically displays the user main interface as the first window (Figure14). This is the entry point for operating with GASMAK2 and provides access to all the other model input interfaces, which are opened as successive windows.

In most applications, menus are one of the main ways that users may issue commands. In this model we use dropdown menus which are visible on the top of the user main interface window. There are five menus in the user main interface: “File”, “Run”, “View”, “Output”, and “Help”. Menu design involves the appropriate arrangement of functions into each menu list and similar options being grouped together so the user just needs to know that the function exists but does not necessarily need to know the names of the functions in the menus. The menus of this model is described as below:

Figure 14: User Main Interface of GASMAK2 Model

File Menu

It is common knowledge that the “File” menu is the beginning of operating a program. The “File” menu for GASMAK2 model is shown in Figure 15.

Figure 15: File Menu for GASMAK2 Model

Run Menu

If the user is satisfied with the input data, using this Run menu shown as Figure 16 to generate the final output information.

Figure 16: Run Menu for GASMAK2 Model

View Menu

User can examine the original data (Point Data, and Well Information) with the “View” menu, shown in Figure 17. A tabular view provides a quick and easy way to display the records that user inputs.

Figure 17: View Menu for GASMAK2 Model

Output Menu

The results of model runs are automatically graphed or tabulated and may be printed out or copied to another application; to retrieve the final results charts using the “Output” menu, there are two commands within this menu (Figure 18).

Figure 18: Output Menu for GASMAK2 Model

Help Menu

A GASMAK2 model help menu is provided, one way to switch between help menu and the work environment. Figure 19 shows the user the help menu.

Figure 19: Help Menu for GASMAK2 Model

It is important to realize that an onboard help system is available for this GASMAK2 model. The help file contains information about GASMAK2 model and the individual input items descriptions. Click on the command of “GASMAK Input Help” from “Help” menu and the Windows Help will pop up (see Figure 20). The first page of this help file is a brief description of the GASMAK2 model.

A hierarchical structure of help topics was chosen for clarity, ease of navigation, and because it reflects the internal structure of GASMAK2. Help topics were designed with consideration for font size, color and layout to improve visual consistency and ease of navigation.

Figure 20: About GASMAK2 Model of Help File

The linkage of the “Individual Input Items descriptions” offer user a list of input parameters organized by input order. The content of individual input items is shown in Figure 21.

Figure 21: Content of Individual Input Items of Help File

With these links, the user can use as first steps in the search for information about each input parameter. An example of an input description for the GASMAK2 model is shown as Figure 22.

Figure 22: An Example of input description for Help File

On the “File” menu, five commands let the user “Input”, “Open”, “Save As”, “Print”, and “Exit” (see figure 14). User can close down all GASMAK2 windows and exits the program using Exit command. Opening, saving, and printing files are basic file management tasks. The user can manage files through this “File” menu efficiently. Each underlined letter in a command is a shortcut to the same action as the corresponding menu item after the menu is open on the screen.

4.3.4.3 Open File Interface

To retrieve a file from disk, choose the “Open” command from the “File” menu, the open dialog box appears, as shown in Figure 23.

Figure 23: Open File Interface for GASMAK2 Model

4.3.4.4 Save As File Interface

Click on the “File” menu; select “Save As”, a classic windows “Save As” dialog appears as Figure 24 to allow the user save files to disk.

Figure 24: Save As File Interface for GASMAK2 Model

4.3.4.5 Print File Interface

Clicking on the “File” menu and selecting “Print” opens a dialog box (Figure 25) with options for printing an image.

Figure 25: Print File Interface for GASMAK2 Model

The establishment of a database is a very important step in the modeling process. The data that are collected must be used answer the questions: What do we have and how does it work? The input interfaces were developed to answer these questions.

To input the initial conditions calculated for GASMAK2 model, choose the "Input" command from the "File" menu, then display the next four interfaces one by one, shown respectively in Figure26, 27, 29, and 30.

The descriptions of inputs and required units for these Figures are described as below.

4.3.4.6 Project and Panel Information Interface

Model input interfaces are used to specify the main driving conditions for model runs and are supplemented by the model input database. Project information and panel information needed for the GASMAK2 model are shown as Figure 26.

The screenshot shows a Windows-style dialog box titled "GASMAK2". Inside the dialog, the title "Project and Panel Information" is centered at the top. Below this title, there are seven input fields arranged in a vertical list, each with a label to its left and a text box to its right. The labels and their corresponding values are: "Project ID:" with "South Block", "Panel Length (ft):" with "5000", "Panel Width (ft):" with "500", "Coal Thickness (ft):" with "6", "Overburden Thickness (ft):" with "1100", "Advance Rate (ft/shift):" with "25", and "Project Life (days):" with "365". To the right of these input fields, there are three buttons stacked vertically: "OK", "Cancel", and "Reset". The dialog box has a standard Windows title bar with minimize, maximize, and close buttons.

Label	Value
Project ID:	South Block
Panel Length (ft):	5000
Panel Width (ft):	500
Coal Thickness (ft):	6
Overburden Thickness (ft):	1100
Advance Rate (ft/shift):	25
Project Life (days):	365

Figure 26: Input Interface of GASMAK2 Model — Project and Panel Information

- **Project ID:**

Any name or descriptive term about project that the user intends to be shown on the output of the final result worksheet. These texts will appear as the heading in the first row of the worksheet.

- **Panel Length (ft):**

The total length of the longwall panel in feet. It is the distance between the out-by rib of the start-up entry and the face location at the recovery point excluding the barrier pillar remaining at the foot of the panel. Refer to the graph of longwall panel layout for determining input to GASMAK2 model shown on the user main interface (figure 14).

- **Panel Width (ft):**

The longwall panel width in feet. It is measured to the outside ribs.

- **Coal Thickness (ft):**

The average extraction thickness (not the coal seam thickness) over the entire longwall panel in feet. For example, if only 72 inches of an 8 feet seam are being extracted, then the input value for the coal thickness would be 6.0 feet.

- **Overburden Thickness (ft):**

The average depth of burial of the longwall panel in feet.

- **Advance Rate (ft/shift):**

The average advance of the longwall face in feet per shift. It is obtained by using an average for a one-week period, or by any reasonable method that the modeler may choose to use. Advance rate is the key parameter in this GASMAK2 model; the higher advance rate will result in more methane emission than lower advance rate, given that the other parameters stay the same.

- **Project Life (days):**

The duration in days of the time period for which there is interest in the gas emissions. The longer project life will generate a greater quantity of output data in the final result worksheet than would extraction time only, and accordingly, the model run time will be greater. Appendix A is a output worksheet based on an input value for project life of 365 days, a panel length of 5000 ft, and an advance rate of 25 ft/shift. At 66.7 elapsed days the mining operation reaches the panel end, but the gas emissions continue into the future. When using this GASMAK2 model for assessing ventilation needs, project life value should be twice of the time it takes to extract the total panel; for economic assessments, it should be extended beyond that.

Other components of this interface include formatted input boxes, and action buttons. Three selections in this interface for user operate this model conveniently:

- “OK”. If the users confirm all the input data are correct, and wish to continue to run this model, then click this button. This will initiate the model with values they have input and bring up the next input interface.
- “Cancel”. This button is designed for the users to exit the input interface without performing any actions and closes this interface.
- “Reset”. If the users are not satisfied with the input data, using this button can set the status of all the input values to empty.

4.3.4.7 Gob Well Calculation Information Interface

This interface consists of gob well information needed for GASMAK2 model shown as Figure 27.

GASMAK2

Gob Well Calculation Information:

First Break Distance (ft):

Segment Length (ft):

Disturbance Zone Multiplier:

Time Increment:

OK

Cancel

Reset

Help

Figure 27: Input Interface of GASMAK2 Model — Gob Well Calculation Information

- **First Break Distance (ft):**

The distance in feet that the longwall face will advance before the first major break will occur in the overlying strata behind the longwall shields.

- **Segment Length (ft):**

The length in feet of the chosen uniform increment of advance. The GASMAK2 model can handle whatever number of segments may be desired, but the smaller each individual segment is, the greater the model run time will be.

- **Disturbance Zone Multiplier:**

This is a value obtained from experience, the number of seam thicknesses above extracted coal that will result in strata movement and stress reduction. It has an impact on the start-up segment emission because strata movement and stress reduction will change the permeability of the gas-bearing strata. The recommended disturbance zone multiplier value is

50~120. For deeper mines, this value should be larger. One may run some parametric analyses to find values that match the history of emission data.

- **Time Increment:**

A value of 1 represents one eight-hour shift. In other words, if we want the contents of the output table shown by one-day increments, then input 3. The larger the time increment is, the shorter the model run time and the less output worksheet will be.

There are four buttons in this interface for user operation, the same functions of “OK”, “Cancel” and “Reset” as in the previous interface. The last button, “Help”, can aid the user in opening the help interface (shown as Figure 28).

4.3.4.8 Help Interface

The longwall panel layout for determining input to GASMAK2 model is a valuable reference to the user for deciding gob well distribution. When inputting initial conditions in the gob well calculation information interface, the users do not need to return to the beginning of the program to refer to this graph. The “OK” button was designed for closing this interface and continuing to input other information.

Figure 28: Help Interface of GASMAK2 Model

4.3.4.9 Gob Well Interface

Figure 29 shows the gob wells interface.

There are many different ways in which users can access the database. DAO (Data Access Objects) is one convention that may be used to access the gob wells database. When using DAO, a table is formed and is declared a 'recordset'. This recordset then makes possible several methods that can be used to manipulate a database. The Edit, AddNew and Delete methods are used in this interface for the main functions. Four command buttons - "Add", "Delete", "Get" and "Update" makes user access to the data for the gob wells easy. Users can import and export data with the gob well information databases using just these four buttons.

The functions of another two buttons, “OK” and “Cancel”, are the same as in the previous interface.

Figure 29: Input Interface of GASMAK2 Model — Gob Well

- **Number of Gob Wells:**

The number of gob degasification wells placed in the longwall panel. The number of gob wells depends on many factors such as the mining technology employed, the ventilation system, the characteristics of the coal seam and mine gas emission, and well size etc. In this model, the number of gob wells is also the number of zones of influence.

- **Location of Gob Wells:**

The distance in feet between panel start-up and each well. (Refer to the graph of the user main interface) In this model, the locations of the gob wells are also the zone change points.

- **Segment “Captured” by Each Well:**

The number of segments in front of each well that will be “captured” by succeeding the gob well. This value should always be less than half of the intervening segments.

4.3.4.10 Data Points Being Input for Emission Curve Interface

The data points being input for the emission curve interface are shown in Figure 30. This interface is designed for using the empirically determined data points subsequently used for emission curve regression. Since the GASMAK2 model interpolates from these data it is best to use as many points as possible and to obtain those points closer together where the curve changes most rapidly.

The image shows a software window titled "GASMAK2" with a subtitle "Data Points Being Input for Emission Curve". Inside the window, there are three input fields: "Point No." with the value "3", "Emission Time (days):" with the value "6", and "Emission Rate(MCFD):" with the value "80". To the right of these fields are four buttons: "Add a new Point", "Delete a Point", "Get a Point", and "Update a Point". At the bottom of the window are "OK" and "Cancel" buttons.

Figure 30: Input Interface of GASMAK2 Model — Data Points Being Input for Emission Curve

- **Point No.:**

The order number of these input data.

- **Emission Time:**

The individual data point times for emission curve, in days. Users do not need to input these data consecutively, because the GASMAK2 model can sort these values automatically for user.

- **Emission Rate:**

The individual data point rates from the emission curve, in thousands of cubic feet daily (MCFD).

Since the GASMAK2 model interpolates the input data, the greater input data, the more accurate the result will be. This could be time-consuming if a lot of data is available. Because of this, the GASMAK2 interface was designed using a database. Microsoft Access is a relational database-management system. It enables one to store, organize, and manipulate collections of information in an electronic format, so that data can be manipulated and extracted with ease and flexibility. Users may not only input these data points from emission curves through Microsoft Access outside of the model, (it is the easier way to input data), but they also can use the four command buttons in this interface - “Add a new Point”, “Delete a Point”, “Get a Point”, and “Uppdate a Point”. These buttons ease access to the data points for emission curves the users do not need to open Microsoft Access itself nor need to know how to run Access. The functions of the other two buttons, “OK” and “Cancel”, are the same as in previous interfaces.

4.3.4.11 Point Data Tabular View Interface

The “Point Data” command from the “View” menu allows the user to read data points being input for emission curve from a table. Figure 31 is a tabular view of the data being input for the emission curve. This table helps user checking the data input.

This interface has the appearance of a spreadsheet, consisting of 3 columns and multiple rows. The first column contains the number of the point being input orderly; the second column contains the emission time value, and the third column contains the emission rate value. This interface is also an input database for the GASMAK2 model.

PointNumber	EmissionTime	EmissionRate
1	1	72.7
2	3	77.6
3	6	80
4	9	79.1
5	12	75.9
6	15	70.6
7	18	64.2
8	24	53.5
9	30	38.5
10	40	27.8
11	50	22
12	60	17.5
13	70	15
14	90	12.8
15	150	11.6
16	250	9.6
17	350	9
18	900	8.6
19	1800	8.3

Figure 31: Point Data Tabular View Interface

4.3.4.12 Gob Well Information Interface

The “Well Information” command from the “View” menu offers the user a table for the gob well information. Figure 32 is an example of a tabular view of the gob well information.

WellNumber	LocationOfGobWell	SegmentCap
1	500	
2	2000	
3	4000	

Figure 32: Gob Well Information Interface

Each of the above two interfaces generate a datasheet which provides a tabular view of the input data. The way to determine which record is active is to examine the left side of the table. A dark triangle in this selection area points to the active record. When a table is larger than the screen, the user can use the vertical and horizontal scroll bars to view fields or records that appear beyond the current viewing area. However, when the user uses the scroll bar, the active record does not change.

4.3.4.13 Run Interface

When the “Start” command on the “Run” menu is pressed where the user has finished inputting all the original data and the GASMAK2 model executes the program code. If the model code requires more than a few seconds to finish, a progress graph (Figure 33) is shown.

Figure 33: Running Interface of GASMAK2 Model

The time that this interface is shown on the screen depends on the project life, and time increment, and complexity of the input data.

Upon completion of a modeling run, GASMAK2 generates outputs which include a worksheet and two charts with respect to the input values (project life, and time increment) in the worksheet. GASMAK2 provides automatically formatted graphs, with labeling and scaling performed from information gathered automatically from the worksheet.

An example of the actual output worksheet from a sample GASMAK2 run is presented in the Appendix A. The worksheet in Microsoft Excel format contains the following information:

- Project time, i.e. the elapsed days
- Longwall face location
- Emission rate for entire longwall panel
- Emission rates for zone 1 to i
- Cumulative gas production for longwall panel
- Cumulative gas production for zones 1 to i

4.3.4.14 Feedback and Error interfaces

One frustration for users of software is the lack of the feedback when the system is processing a long task. Unfortunately, users will always find situations where an error may occur. In the design stage of the GASMAK2 model, as many error situations as possible were anticipated and mechanisms were provided to prevent users from setting up these situations by displaying suitable warning messages. Error messages are, where possible, constructive and offer the user some constructive help in suggesting remedies for the situations. Many error message boxes were designed during the development of this GASMAK2 model. Figure 34 and

35 show two examples. The popup message box warns the user and offers some information to run the program correctly.

Figure 34: Error Message Box for GASMAK2 Model (1)

Numerical entries from the user are range and type checked for validity before acceptance for a model run.

Figure 35: Error Message Box for GASMAK2 Model (2)

4.4 GASMAK2 Model Discussion

The GASMAK2 model gives a quick visual representations (Figure 36 and Figure 37) of model results, depicting the gas emission rate at various times of mining activities and the emitted gas volume as a function of project time.

4.4.1 GASMAK2 Model Example Output Characteristic

Figure 36 is an illustration of a GASMAK2 model output graph. From a profile of methane emission rate versus time one can see that there is a characteristic decline curve for gas

Figure 36: Gas Emission Rate Chart for GASMAK2 Model

emission rates follows the exponential pattern established by Airey. The reason for the early growth of the curve characteristic is that during the early stages of production, methane emission rates increase while strata subsides and fractures followed by a peak in methane emission rate when equilibrium is reached and then a long asymptotic decline. An adequate period of production is necessary in the beginning to establish the equilibrium decline pattern. As for the decline side of the curve, it may be disturbed somewhat if the production from the subject well is interfered with by adjacent wells. This curve can be used to fit the gas emission rate versus time data of production properties.

The rapid drop from the peak and the nonzero start of each zone is an artifact of the manner in which gob wells work and the mining process that creates the gas flow. Gob wells produce nothing until they are undermined and the strata that they penetrate are subsequently deformed. After mining, they start producing gas immediately, because their influence extends

some distance into the previously created gob area. GASMAK2 accounts for this by assigning a portion of the previous well's zone of influence to the newly active zone as each gob well is undermined. The last zone, having no such gob area transfer, shows no such decline.

Each coal has a characteristic “desorption time” that includes the time required for methane molecules to desorb off the coal surface and diffuse through the coal into the cleat system. The coal’s sorption time can vary from less than one to over 300 days depending on coal composition, cleat spacing, and reservoir pressure. The rate at which methane desorbs and diffuses determines the stage in the coal mining and utilization process at which the methane is emitted. A coal with a short sorption time of one or two days, for example, will emit most of its methane during mining operations, while a coal with a long sorption time of 100-200 days will emit much of its methane during post mining coal processing.

Figure 37: Total Gas Emission Volumes Chart for GASMAK2 Model

Figure 37 is an example of GASMAK2 model output chart. The profile is same as the one from standard Airey curve (refer to Figure 7, chapter 3).

4.4.2 Comparison With Other Models

GASMAK2 model has been tested and validated against two other gas prediction models, they are the Australia Lunagas model (refer to chapter 2) and the CFD (Computational Fluid Dynamics) model. The output charts predicted by these two models are shown in Figure 38 and Figure 39. The knowledge and quantitative information about the two models are very limited. Further study is needed to improve the understanding of the difference between these models. However, the profile comparison at this stage is good.

Figure 38: Total Methane Produced from 16 Gob Wells in 3 Panels (Australia Model)

Figure 39: Predicted Gob Well Production Rates from CFD Model

(from Coal mine methane resources estimation and reserve evaluation)

The CFD model tracks material balances and uses the storage and flow characteristics of methane in coal, as well as other reservoir rocks, to provide a production forecast for a given recovery technique. This model uses numerical techniques to predict the gas emission rate into roadways or production into wellbores. Figure 39 shows the predicted production rates for three gob wells drilled into a longwall panel gob area.

When the GASMAK2 model was verified with the above two models, in the comparison with the output profiles, it can be seen that the predicted profiles by GASMAK2 model are in good agreement with the other models. The gas emission rate profiles predicted by GASMAK2 model were very close to those predicted by the numerical model and the statistical model. The curves have the same shape. The gas emission rates for these three model graphs are somewhat different. Several possible reasons for this difference include, geological conditions and mining technology. The geological conditions may include stratum, structure, thickness and structure

characteristics of coal seams, gas content, gas pressure and drainage ability. Mining technology difference may include driving methods, working face size, and advance rate.

4.5 Hardware and Software Requirements

The computer program for the GASMAK2 model has been developed on a standard 586 computer. For general use, the recommended system configuration to use this program is Microsoft Windows 98 or later on a personal computer with a Pentium III processor, 128 megabytes (MB) of RAM, 10G Hard disk space and super VGA (800 x 600) or higher-resolution monitor with 256 colors. Also, Microsoft Visual Basic 6.0 compiler, Microsoft Excel 2000 and Microsoft Access 2000 are required to run the program.

Chapter 5 Summary

The GASMAK2 model had the development of a Windows based empirical model of methane emissions for Gob well as its goal. It is 'empirical' because the methods and principles involved are based on observation and experiment. It was successful in the meeting its initial major goals, but much remains to be expanded and improved. The main objective - development of a Windows-based model for longwall gob gas emission - was achieved.

The GASMAK2 model is capable of quantifying the emission changes over time in longwall gob areas. The flow of methane gas from a coal bed that is being actively mined is very difficult to measure accurately; it must be predicted from the known properties of the bed. The GASMAK2 does not imulate the fundamental concepts governing the transport of gases through coal beds. However, it is an excellent approximation. Reasonable evaluation of the methane in a coal mine depends on a knowledge of production rate through time, and the use of this model in a good experimental program should clearly indicate what future developments are needed for methane control.

The strengths and successes of this GASMAK2 model in general include:

- The GASMAK2 model utilizes the convenience features of Windows such as a point-and-click Windows-based user interface, onboard help files, input database, and automatic final chart. This program is user friendly, intuitive, and easy to use;
- The GASMAK2 model is fast, and it requires simple input data; it represents a substantial increase in the efficiency of the original GASMAK model.
- The GASMAK2 model is simple to understand and may be easily adapted to existing gas emission estimates;

- Comparison computations measurements with other models prove shows a good match, and it accurately reflects gob gas emission;
- This model can be used to predict future emission related to mine expansion.

The weaknesses of this approach are:

- Initial data is required to use the GASMAK2;
- Between adjacent sites variability may be high, and much of the variability cannot be accounted for in the GASMAK2 model.
- The model would benefit if mining rates could be made variable over a project life.

The GASMAK2 model provides user a useful tool for visualizing, assessing and designing methane control needs. Because the output is based on empirical input, it does not rely on reservoir properties. As with any computer model, the accuracy of the output will depend upon the care taken with obtaining the input data. The more reliable the input data, the better the quality of the resulting output.

Chapter 6 Conclusions and Suggestions for Further Work

6.1 Conclusions

The GASMAK model was an empirical model that was initially reported in 1997 by Dr. Lloyd M. English. Here it is further developed as a Windows based program - GASMAK2 model by the author for his master thesis.

This thesis discusses the development of an empirical model that describes the generation of methane for longwall gob areas. The goal for the development of this model is to make it more useful as an aid in the determination of the number, size and location of vertical gob wells or other methane control application that are needed for gob gas control.

The research presented in this thesis addresses the problems of empirical model development for assessing gob gas control requirements. Several contributions toward the resolution of the problems have been made.

The design of a user interface is the crux of the development of any software system. In recent years, software projects have been devoting more to the design of the interface than the actual underlying application code. This may be a sign of a competitive market, where the users are demanding more sophisticated software interfaces, and frequently understand less about the problem itself.

The original GASMAK model is written in the Fortran Programming Language and it produced an output data table, but it must be loaded into a spreadsheet for visualization. The user must also prepare an input table in an appropriate DOS-based format for the GASMAK model to read in advance. The GASMAK2 model was developed specifically to make users this model for the convenience of the user. The GASMAK2 program offers a user-friendly interface, generates the spreadsheet, and creates the charts automatically. There are some new features in

the GASMAK2 model for its input database, help file system and automation. It is a substantial enhancement to the original GASMAK model. A significant advantage of GASMAK2 model is that only one of the input data is needed to be measured, i.e. data points being input for emission curve, and which may be obtained from experiment. If there are no experiments for these data, the user can obtain historical data from same region or similar geological conditions. Comparisons of profiles have demonstrated that the profiles predicted by using GASMAK2 model are, in general, in good agreement with those predicted by other models. They have same shape profiles.

However, the GASMAK2 model is by no means completely developed. The remainder of this chapter presents some future directions for improving this GASMAK2 model.

6.2 The Work Needed for Improving the Model

Although the work carried out in this thesis has a substantial improvement to GASMAK model, it has revealed many promising areas of further work in GASMAK2 model development and some potential technical improvements would make this model even more useful. A few improvements worthy of further consideration can be briefly summarized as follows:

- Developing of nonlinear regression for determining the rate of methane emission. The GASMAK2 model is based on the Airey equation. Sometimes if a known geological anomaly were associated with a panel under construction, the mathematics theory of Newton or Conjugate method could be used to adjust the Airey equation accordingly.
- Modifying of GASMAK2 model for room-and-pillar operations. Currently, underground coal production in the U.S. is split almost 50-50 between large longwall

mines and smaller room-and-pillar mines. Right now, the GASMAK2 model is designed for longwall mining operations. A modified model could be used to make emission estimates for full extraction room-and-pillar mining operations.

- Automatic drawing of panel layout graph using AutoCAD Development System (ADS) as an interactive graphical programming environment. ADS is a compiled-language program environment for developing AutoCAD applications, and an improved GASMAK2 model could offer the user a graphic map including gob well information, well number, size, location, and more, within panel.
- Developing of the "Query" tool for total methane volumes, peak emission rates value, time period captured by each well, and more. A typical search of the database is to help users find model results more easily. This modification can be made using SQL "Structured Query Language".
- Modeling a block of panels. GASMAK2 was developed for single longwall panel gas emissions. All the coal mines using longwall mining systems use blocks of panels. The model for a block of panels is even more practical.
- Enabling the use of varying coal production rates or the inclusion of down-time.

It should be noted that the above suggestions for further model development would be enhanced by user-input.

Outputs from this GASMAK2 model are used to design gas drainage technologies, and gas wells drilled from the surface. Because the volume of gas that is liberated during mining for a given period is also available, developers of coal mine can use this data to determine the specific emissions that must be controlled. They may also used for precise gas production

predictions and the assessment of gas conditions necessary for planning commercial gas operations.

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Appendix

Appendix A Output Spreadsheet for GASMAK2 Model

Days	Face	Panel Rate	Zone 1 Rate	Zone 2 Rate	Zone 3 Rate	Panel Cum. Gas	Zone 1 Gas	Zone 2 Gas	Zone 3 Gas
0.3	25	0	0	0	0	0	0	0	0
0.7	50	0	0	0	0	0	0	0	0
1.0	75	0	0	0	0	0	0	0	0
1.3	100	0	0	0	0	0	0	0	0
1.7	125	0	0	0	0	0	0	0	0
2.0	150	0	0	0	0	0	0	0	0
2.3	175	0	0	0	0	0	0	0	0
2.7	200	0	0	0	0	0	0	0	0
3.0	225	74	74	0	0	25	25	0	0
3.3	250	148	148	0	0	74	74	0	0
3.7	275	223	223	0	0	148	148	0	0
4.0	300	299	299	0	0	248	248	0	0
4.3	325	376	376	0	0	373	373	0	0
4.7	350	453	453	0	0	524	524	0	0
5.0	375	531	531	0	0	701	701	0	0
5.3	400	609	609	0	0	904	904	0	0
5.7	425	688	688	0	0	1134	1134	0	0
6.0	450	766	766	0	0	1389	1389	0	0
6.3	475	845	845	0	0	1671	1671	0	0
6.7	500	925	925	0	0	1979	1979	0	0
7.0	525	1004	1004	0	0	2314	2314	0	0
7.3	550	1084	1084	0	0	2675	2675	0	0
7.7	575	1164	1164	0	0	3063	3063	0	0
8.0	600	1244	1244	0	0	3477	3477	0	0
8.3	625	1323	1323	0	0	3919	3919	0	0
8.7	650	1403	1403	0	0	4386	4386	0	0
9.0	675	1483	1483	0	0	4881	4881	0	0
9.3	700	1562	1562	0	0	5401	5401	0	0
9.7	725	1642	1642	0	0	5948	5948	0	0
10.0	750	1721	1721	0	0	6522	6522	0	0
10.3	775	1800	1800	0	0	7122	7122	0	0
10.7	800	1879	1879	0	0	7749	7749	0	0
11.0	825	1958	1958	0	0	8401	8401	0	0
11.3	850	2036	2036	0	0	9080	9080	0	0
11.7	875	2114	2114	0	0	9785	9785	0	0
12.0	900	2192	2192	0	0	10516	10516	0	0
12.3	925	2269	2269	0	0	11272	11272	0	0
12.7	950	2346	2346	0	0	12054	12054	0	0
13.0	975	2423	2423	0	0	12862	12862	0	0
13.3	1000	2499	2499	0	0	13695	13695	0	0
13.7	1025	2575	2575	0	0	14553	14553	0	0
14.0	1050	2650	2650	0	0	15437	15437	0	0
14.3	1075	2725	2725	0	0	16345	16345	0	0
14.7	1100	2799	2799	0	0	17278	17278	0	0
15.0	1125	2873	2873	0	0	18236	18236	0	0
15.3	1150	2946	2946	0	0	19218	19218	0	0
15.7	1175	3018	3018	0	0	20224	20224	0	0
16.0	1200	3090	3090	0	0	21254	21254	0	0
16.3	1225	3161	3161	0	0	22308	22308	0	0
16.7	1250	3232	3232	0	0	23385	23385	0	0
17.0	1275	3302	3302	0	0	24485	24485	0	0
17.3	1300	3371	3371	0	0	25609	25609	0	0
17.7	1325	3439	3439	0	0	26755	26755	0	0
18.0	1350	3507	3507	0	0	27924	27924	0	0
18.3	1375	3574	3574	0	0	29116	29116	0	0
18.7	1400	3640	3640	0	0	30329	30329	0	0
19.0	1425	3706	3706	0	0	31565	31565	0	0

19.3	1450	3771	3771	0	0	32822	32822	0	0
19.7	1475	3835	3835	0	0	34100	34100	0	0
20.0	1500	3899	3899	0	0	35400	35400	0	0
20.3	1525	3962	3962	0	0	36720	36720	0	0
20.7	1550	4024	4024	0	0	38062	38062	0	0
21.0	1575	4086	4086	0	0	39424	39424	0	0
21.3	1600	4147	4147	0	0	40806	40806	0	0
21.7	1625	4208	4208	0	0	42209	42209	0	0
22.0	1650	4268	4268	0	0	43631	43631	0	0
22.3	1675	4327	4327	0	0	45074	45074	0	0
22.7	1700	4386	4386	0	0	46536	46536	0	0
23.0	1725	4444	4444	0	0	48017	48017	0	0
23.3	1750	4502	4502	0	0	49518	49518	0	0
23.7	1775	4559	4559	0	0	51038	51038	0	0
24.0	1800	4616	4616	0	0	52576	52576	0	0
24.3	1825	4672	4672	0	0	54133	54133	0	0
24.7	1850	4727	4727	0	0	55709	55709	0	0
25.0	1875	4782	4782	0	0	57303	57303	0	0
25.3	1900	4836	4836	0	0	58915	58915	0	0
25.7	1925	4889	4889	0	0	60544	60544	0	0
26.0	1950	4942	4942	0	0	62192	62192	0	0
26.3	1975	4994	4994	0	0	63856	63856	0	0
26.7	2000	5045	3721	1323	0	65538	65097	441	0
27.0	2025	5095	3692	1403	0	67236	66327	909	0
27.3	2050	5144	3661	1483	0	68951	67548	1403	0
27.7	2075	5193	3630	1562	0	70682	68758	1924	0
28.0	2100	5240	3599	1642	0	72428	69957	2471	0
28.3	2125	5287	3566	1721	0	74191	71146	3045	0
28.7	2150	5333	3533	1800	0	75968	72324	3645	0
29.0	2175	5378	3499	1879	0	77761	73490	4271	0
29.3	2200	5423	3465	1958	0	79569	74645	4924	0
29.7	2225	5466	3430	2036	0	81391	75788	5603	0
30.0	2250	5509	3394	2114	0	83227	76920	6307	0
30.3	2275	5551	3359	2192	0	85077	78039	7038	0
30.7	2300	5592	3322	2269	0	86941	79146	7795	0
31.0	2325	5632	3285	2346	0	88818	80242	8577	0
31.3	2350	5671	3248	2423	0	90709	81324	9384	0
31.7	2375	5710	3210	2499	0	92612	82394	10218	0
32.0	2400	5748	3173	2575	0	94528	83452	11076	0
32.3	2425	5786	3135	2650	0	96456	84497	11959	0
32.7	2450	5823	3098	2725	0	98397	85530	12868	0
33.0	2475	5860	3061	2799	0	100351	86550	13801	0
33.3	2500	5897	3024	2873	0	102316	87558	14759	0
33.7	2525	5933	2987	2946	0	104294	88554	15740	0
34.0	2550	5969	2951	3018	0	106284	89537	16747	0
34.3	2575	6005	2915	3090	0	108285	90509	17777	0
34.7	2600	6040	2879	3161	0	110299	91468	18830	0
35.0	2625	6075	2843	3232	0	112324	92416	19907	0
35.3	2650	6110	2808	3302	0	114360	93352	21008	0
35.7	2675	6144	2773	3371	0	116408	94276	22132	0
36.0	2700	6178	2738	3439	0	118467	95189	23278	0
36.3	2725	6211	2704	3507	0	120538	96091	24447	0
36.7	2750	6244	2670	3574	0	122619	96981	25638	0
37.0	2775	6277	2637	3640	0	124711	97860	26852	0
37.3	2800	6310	2603	3706	0	126815	98727	28087	0
37.7	2825	6342	2571	3771	0	128928	99584	29344	0
38.0	2850	6373	2538	3835	0	131053	100430	30623	0
38.3	2875	6405	2506	3899	0	133188	101266	31922	0
38.7	2900	6436	2474	3962	0	135333	102090	33243	0

39.0	2925	6466	2442	4024	0	137489	102904	34584	0
39.3	2950	6497	2411	4086	0	139654	103708	35946	0
39.7	2975	6527	2379	4147	0	141830	104501	37329	0
40.0	3000	6556	2348	4208	0	144015	105284	38731	0
40.3	3025	6585	2318	4268	0	146210	106056	40154	0
40.7	3050	6614	2287	4327	0	148415	106819	41596	0
41.0	3075	6643	2257	4386	0	150629	107571	43058	0
41.3	3100	6671	2226	4444	0	152853	108313	44540	0
41.7	3125	6699	2197	4502	0	155086	109045	46041	0
42.0	3150	6726	2167	4559	0	157328	109767	47560	0
42.3	3175	6754	2138	4616	0	159579	110480	49099	0
42.7	3200	6781	2109	4672	0	161840	111183	50656	0
43.0	3225	6808	2081	4727	0	164109	111877	52232	0
43.3	3250	6835	2053	4782	0	166388	112561	53825	0
43.7	3275	6861	2026	4836	0	168675	113237	55437	0
44.0	3300	6888	1999	4889	0	170971	113903	57067	0
44.3	3325	6914	1972	4942	0	173276	114561	58714	0
44.7	3350	6940	1947	4994	0	175589	115209	60379	0
45.0	3375	6966	1922	5045	0	177911	115850	62060	0
45.3	3400	6992	1897	5095	0	180242	116482	63759	0
45.7	3425	7017	1873	5144	0	182581	117107	65473	0
46.0	3450	7043	1850	5193	0	184928	117723	67204	0
46.3	3475	7068	1827	5240	0	187284	118332	68951	0
46.7	3500	7093	1805	5287	0	189649	118934	70713	0
47.0	3525	7117	1784	5333	0	192021	119529	72491	0
47.3	3550	7142	1764	5378	0	194402	120117	74284	0
47.7	3575	7166	1743	5423	0	196790	120698	76091	0
48.0	3600	7190	1724	5466	0	199187	121273	77913	0
48.3	3625	7214	1705	5509	0	201592	121841	79750	0
48.7	3650	7238	1687	5551	0	204005	122403	81600	0
49.0	3675	7261	1670	5592	0	206425	122960	83464	0
49.3	3700	7285	1653	5632	0	208853	123511	85341	0
49.7	3725	7308	1637	5671	0	211289	124057	87231	0
50.0	3750	7331	1621	5710	0	213733	124597	89135	0
50.3	3775	7354	1606	5748	0	216184	125132	91050	0
50.7	3800	7376	1591	5786	0	218643	125663	92979	0
51.0	3825	7399	1576	5823	0	221109	126188	94920	0
51.3	3850	7421	1561	5860	0	223583	126708	96873	0
51.7	3875	7443	1546	5897	0	226064	127224	98839	0
52.0	3900	7465	1532	5933	0	228552	127734	100817	0
52.3	3925	7486	1517	5969	0	231048	128240	102806	0
52.7	3950	7508	1503	6005	0	233551	128741	104808	0
53.0	3975	7529	1489	6040	0	236060	129237	106821	0
53.3	4000	7551	1476	4752	1323	238577	129729	108405	441
53.7	4025	7572	1462	4706	1403	241101	130217	109974	909
54.0	4050	7593	1449	4661	1483	243632	130699	111527	1403
54.3	4075	7613	1436	4615	1562	246170	131178	113066	1924
54.7	4100	7634	1423	4570	1642	248715	131652	114589	2471
55.0	4125	7655	1410	4523	1721	251266	132123	116097	3045
55.3	4150	7675	1398	4477	1800	253825	132588	117589	3645
55.7	4175	7695	1386	4430	1879	256390	133050	119066	4271
56.0	4200	7715	1374	4384	1958	258962	133508	120527	4924
56.3	4225	7735	1362	4337	2036	261540	133962	121973	5603
56.7	4250	7755	1350	4290	2114	264125	134412	123403	6307
57.0	4275	7774	1339	4244	2192	266716	134859	124817	7038
57.3	4300	7794	1328	4197	2269	269314	135301	126216	7795
57.7	4325	7813	1317	4150	2346	271918	135740	127600	8577
58.0	4350	7832	1306	4104	2423	274529	136175	128968	9384
58.3	4375	7851	1295	4057	2499	277146	136607	130320	10218

58.7	4400	7870	1285	4010	2575	279769	137035	131657	11076
59.0	4425	7889	1275	3964	2650	282399	137460	132978	11959
59.3	4450	7907	1265	3918	2725	285034	137882	134284	12868
59.7	4475	7926	1255	3872	2799	287676	138300	135575	13801
60.0	4500	7944	1245	3826	2873	290324	138715	136850	14759
60.3	4525	7962	1236	3781	2946	292978	139127	138110	15740
60.7	4550	7980	1226	3736	3018	295638	139536	139355	16747
61.0	4575	7998	1217	3691	3090	298304	139942	140586	17777
61.3	4600	8016	1208	3647	3161	300975	140344	141801	18830
61.7	4625	8033	1198	3603	3232	303653	140744	143002	19907
62.0	4650	8051	1189	3560	3302	306336	141140	144189	21008
62.3	4675	8068	1180	3517	3371	309025	141533	145361	22132
62.7	4700	8085	1171	3475	3439	311720	141924	146520	23278
63.0	4725	8102	1162	3433	3507	314421	142311	147664	24447
63.3	4750	8119	1153	3392	3574	317127	142696	148795	25638
63.7	4775	8136	1145	3351	3640	319839	143077	149912	26852
64.0	4800	8153	1136	3311	3706	322556	143456	151016	28087
64.3	4825	8170	1128	3272	3771	325280	143832	152106	29344
64.7	4850	8187	1119	3233	3835	328008	144205	153184	30623
65.0	4875	8204	1111	3194	3899	330743	144575	154248	31922
65.3	4900	8220	1103	3155	3962	333483	144943	155300	33243
65.7	4925	8237	1095	3118	4024	336228	145308	156340	34584
66.0	4950	8253	1087	3080	4086	338979	145670	157366	35946
66.3	4975	8269	1079	3043	4147	341735	146030	158381	37329
66.7	5000	8286	1071	3006	4208	344497	146387	159383	38731
67.0	5000	8302	1064	2970	4268	347264	146742	160373	40154
67.3	5000	8318	1056	2934	4327	350036	147094	161351	41596
67.7	5000	8334	1049	2899	4386	352814	147444	162317	43058
68.0	5000	8276	1042	2863	4371	355573	147791	163271	44515
68.3	5000	8218	1035	2829	4354	358312	148136	164214	45967
68.7	5000	8158	1028	2795	4336	361031	148478	165146	47412
69.0	5000	8098	1021	2761	4317	363730	148819	166066	48851
69.3	5000	8037	1014	2727	4296	366409	149157	166975	50283
69.7	5000	7975	1007	2694	4273	369067	149492	167873	51708
70.0	5000	7912	1001	2661	4250	371704	149826	168760	53124
70.3	5000	7849	994	2629	4226	374321	150157	169637	54533
70.7	5000	7786	988	2597	4201	376916	150487	170502	55933
71.0	5000	7723	981	2566	4175	379490	150814	171358	57325
71.3	5000	7659	975	2536	4148	382043	151139	172203	58708
71.7	5000	7595	969	2506	4120	384574	151462	173038	60081
72.0	5000	7530	963	2477	4091	387084	151783	173864	61445
72.3	5000	7465	957	2449	4060	389573	152102	174680	62798
72.7	5000	7400	951	2421	4029	392039	152419	175487	64141
73.0	5000	7335	945	2394	3997	394484	152734	176285	65474
73.3	5000	7270	939	2368	3964	396908	153047	177074	66795
73.7	5000	7205	934	2342	3930	399309	153358	177855	68105
74.0	5000	7141	928	2317	3896	401689	153667	178627	69403
74.3	5000	7076	923	2293	3860	404048	153975	179392	70690
74.7	5000	7011	918	2269	3824	406385	154281	180148	71965
75.0	5000	6946	912	2246	3788	408700	154585	180897	73228
75.3	5000	6882	907	2224	3750	410994	154888	181638	74478
75.7	5000	6817	903	2202	3712	413266	155188	182372	75715
76.0	5000	6753	898	2181	3674	415517	155488	183099	76940
76.3	5000	6689	893	2161	3635	417746	155785	183820	78151
76.7	5000	6626	889	2142	3595	419955	156082	184534	79350
77.0	5000	6562	884	2122	3556	422142	156376	185241	80535
77.3	5000	6499	880	2103	3516	424308	156670	185942	81707
77.7	5000	6437	876	2084	3477	426454	156962	186637	82866
78.0	5000	6374	872	2066	3437	428578	157252	187326	84011

78.3	5000	6312	868	2047	3398	430682	157541	188008	85144
78.7	5000	6251	864	2029	3358	432766	157829	188685	86263
79.0	5000	6190	860	2011	3319	434829	158116	189355	87370
79.3	5000	6129	856	1993	3280	436872	158401	190020	88463
79.7	5000	6069	853	1976	3241	438895	158686	190678	89543
80.0	5000	6010	849	1958	3202	440898	158969	191331	90610
80.3	5000	5951	846	1941	3164	442881	159251	191978	91665
80.7	5000	5892	843	1924	3126	444845	159532	192619	92707
81.0	5000	5835	839	1907	3088	446790	159811	193255	93736
81.3	5000	5777	836	1891	3050	448715	160090	193886	94753
81.7	5000	5721	833	1875	3013	450622	160368	194511	95757
82.0	5000	5665	830	1859	2975	452510	160644	195131	96749
82.3	5000	5609	827	1844	2939	454380	160920	195745	97728
82.7	5000	5554	824	1828	2902	456231	161194	196355	98696
83.0	5000	5500	821	1814	2866	458065	161468	196959	99651
83.3	5000	5447	818	1799	2831	459880	161741	197559	100595
83.7	5000	5395	815	1784	2795	461678	162012	198154	101526
84.0	5000	5343	812	1770	2760	463459	162283	198744	102446
84.3	5000	5291	809	1756	2726	465223	162553	199329	103355
84.7	5000	5241	806	1743	2691	466969	162821	199910	104252
85.0	5000	5191	804	1729	2657	468699	163089	200487	105138
85.3	5000	5141	801	1716	2624	470413	163356	201059	106013
85.7	5000	5092	798	1704	2590	472110	163622	201627	106876
86.0	5000	5044	796	1691	2557	473791	163888	202191	107728
86.3	5000	4996	793	1679	2524	475456	164152	202750	108569
86.7	5000	4949	791	1667	2491	477106	164416	203306	109400
87.0	5000	4902	788	1655	2458	478740	164678	203858	110219
87.3	5000	4856	786	1643	2426	480358	164940	204405	111028
87.7	5000	4810	784	1632	2395	481961	165202	204949	111826
88.0	5000	4765	781	1620	2364	483550	165462	205489	112614
88.3	5000	4720	779	1609	2333	485123	165722	206026	113392
88.7	5000	4677	777	1597	2302	486682	165981	206558	114159
89.0	5000	4633	775	1586	2272	488226	166239	207087	114916
89.3	5000	4590	773	1575	2243	489756	166496	207612	115664
89.7	5000	4548	771	1564	2213	491272	166753	208133	116402
90.0	5000	4506	769	1553	2185	492774	167009	208651	117130
90.3	5000	4465	767	1543	2156	494262	167265	209165	117849
90.7	5000	4425	765	1532	2128	495737	167520	209676	118558
91.0	5000	4385	762	1522	2101	497199	167774	210183	119258
91.3	5000	4346	760	1511	2074	498647	168027	210687	119950
91.7	5000	4308	758	1501	2048	500083	168280	211187	120632
92.0	5000	4270	756	1491	2022	501506	168532	211685	121307
92.3	5000	4234	755	1482	1998	502917	168784	212178	121972
92.7	5000	4198	753	1472	1973	504317	169035	212669	122630
93.0	5000	4163	751	1462	1950	505704	169285	213157	123280
93.3	5000	4129	749	1453	1927	507080	169535	213641	123923
93.7	5000	4096	747	1444	1905	508446	169784	214122	124557
94.0	5000	4063	745	1435	1883	509800	170032	214601	125185
94.3	5000	4032	743	1426	1862	511144	170280	215076	125806
94.7	5000	4001	742	1418	1842	512477	170527	215549	126420
95.0	5000	3971	740	1409	1822	513801	170774	216019	127027
95.3	5000	3942	738	1401	1803	515115	171020	216485	127628
95.7	5000	3914	737	1392	1785	516419	171265	216950	128223
96.0	5000	3886	735	1384	1767	517714	171510	217411	128812
96.3	5000	3860	733	1377	1750	519001	171755	217870	129395
96.7	5000	3834	732	1369	1733	520279	171999	218326	129973
97.0	5000	3808	730	1361	1717	521548	172242	218780	130545
97.3	5000	3783	729	1354	1701	522809	172485	219231	131112
97.7	5000	3759	727	1346	1685	524062	172727	219680	131674

98.0	5000	3734	726	1339	1669	525307	172969	220127	132230
98.3	5000	3710	724	1332	1654	526544	173211	220571	132782
98.7	5000	3686	723	1325	1639	527773	173452	221012	133328
99.0	5000	3663	722	1318	1624	528994	173692	221451	133869
99.3	5000	3640	720	1311	1609	530207	173932	221888	134405
99.7	5000	3617	719	1304	1594	531413	174172	222323	134937
100.0	5000	3595	718	1298	1580	532612	174411	222756	135463
100.3	5000	3573	717	1291	1565	533803	174650	223186	135985
100.7	5000	3552	715	1285	1551	534987	174889	223615	136502
101.0	5000	3530	714	1279	1538	536164	175127	224041	137015
101.3	5000	3509	713	1272	1524	537334	175365	224465	137523
101.7	5000	3489	712	1266	1511	538497	175602	224887	138026
102.0	5000	3469	711	1260	1497	539653	175839	225307	138526
102.3	5000	3449	710	1255	1484	540803	176075	225726	139020
102.7	5000	3429	709	1249	1472	541946	176312	226142	139511
103.0	5000	3410	708	1243	1459	543083	176548	226556	139997
103.3	5000	3391	707	1238	1447	544213	176783	226969	140480
103.7	5000	3373	706	1233	1434	545338	177019	227380	140958
104.0	5000	3355	705	1227	1423	546456	177254	227789	141432
104.3	5000	3337	704	1222	1411	547568	177488	228196	141902
104.7	5000	3320	703	1217	1399	548675	177723	228602	142369
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105.7	5000	3270	701	1203	1366	551961	178424	229810	143746
106.0	5000	3254	700	1198	1355	553046	178658	230209	144197
106.3	5000	3238	699	1194	1345	554125	178891	230607	144646
106.7	5000	3223	699	1190	1334	555200	179124	231004	145090
107.0	5000	3207	698	1185	1324	556269	179357	231399	145532
107.3	5000	3193	698	1181	1314	557334	179589	231792	145970
107.7	5000	3178	697	1177	1304	558393	179822	232185	146405
108.0	5000	3163	696	1173	1294	559448	180054	232575	146836
108.3	5000	3149	696	1169	1285	560498	180286	232965	147264
108.7	5000	3135	695	1164	1275	561543	180517	233353	147689
109.0	5000	3121	695	1160	1265	562584	180749	233740	148111
109.3	5000	3107	694	1157	1256	563619	180981	234125	148530
109.7	5000	3093	694	1153	1247	564651	181212	234510	148945
110.0	5000	3080	694	1149	1237	565678	181443	234893	149358
110.3	5000	3067	693	1145	1228	566700	181675	235274	149767
110.7	5000	3054	693	1141	1219	567718	181906	235655	150174
111.0	5000	3041	693	1138	1210	568732	182137	236034	150577
111.3	5000	3028	692	1134	1202	569741	182367	236412	150978
111.7	5000	3016	692	1131	1193	570746	182598	236789	151376
112.0	5000	3003	692	1127	1185	571747	182829	237164	151770
112.3	5000	2991	691	1124	1176	572744	183059	237539	152163
112.7	5000	2979	691	1121	1168	573738	183289	237912	152552
113.0	5000	2967	690	1117	1160	574727	183519	238285	152938
113.3	5000	2956	690	1114	1151	575712	183750	238656	153322
113.7	5000	2944	690	1111	1143	576693	183979	239027	153703
114.0	5000	2933	689	1108	1136	577671	184209	239396	154082
114.3	5000	2922	689	1105	1128	578645	184439	239765	154458
114.7	5000	2911	689	1103	1120	579615	184669	240132	154831
115.0	5000	2901	688	1100	1113	580582	184898	240499	155202
115.3	5000	2890	688	1097	1105	581546	185127	240865	155571
115.7	5000	2880	688	1095	1098	582506	185357	241230	155937
116.0	5000	2870	687	1092	1091	583463	185586	241594	156300
116.3	5000	2860	687	1090	1084	584416	185815	241957	156661
116.7	5000	2850	686	1088	1077	585366	186043	242319	157020
117.0	5000	2841	686	1085	1070	586313	186272	242681	157377
117.3	5000	2831	686	1083	1063	587257	186501	243042	157731

117.7	5000	2822	685	1081	1056	588198	186729	243402	158083
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124.7	5000	2661	678	1041	943	607324	191499	250812	165031
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125.7	5000	2643	677	1036	930	609972	192176	251850	165965
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139.7	5000	2473	661	998	814	645606	201537	266025	178067
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203.3	5000	2187	591	896	700	792891	241386	326280	225251
203.7	5000	2185	591	895	699	793620	241582	326578	225484
204.0	5000	2184	590	895	699	794348	241779	326876	225717
204.3	5000	2183	590	894	699	795075	241976	327174	225950
204.7	5000	2181	590	894	698	795803	242172	327472	226182
205.0	5000	2180	589	893	698	796529	242369	327770	226415
205.3	5000	2179	589	893	697	797256	242565	328068	226647
205.7	5000	2178	589	892	697	797981	242761	328365	226880
206.0	5000	2176	588	891	697	798707	242957	328662	227112
206.3	5000	2175	588	891	696	799432	243153	328959	227344
206.7	5000	2174	587	890	696	800156	243349	329256	227576
207.0	5000	2172	587	890	695	800880	243545	329552	227808
207.3	5000	2171	587	889	695	801604	243740	329849	228039
207.7	5000	2170	586	889	695	802327	243936	330145	228271
208.0	5000	2168	586	888	694	803050	244131	330441	228502
208.3	5000	2167	586	888	694	803772	244326	330737	228733
208.7	5000	2166	585	887	693	804494	244521	331033	228964
209.0	5000	2165	585	887	693	805215	244716	331328	229195
209.3	5000	2163	584	886	693	805936	244911	331624	229426
209.7	5000	2162	584	886	692	806657	245106	331919	229657
210.0	5000	2161	584	885	692	807377	245301	332214	229887
210.3	5000	2159	583	885	691	808097	245495	332509	230118
210.7	5000	2158	583	884	691	808816	245689	332803	230348
211.0	5000	2157	583	883	691	809535	245884	333098	230578
211.3	5000	2155	582	883	690	810253	246078	333392	230808
211.7	5000	2154	582	882	690	810971	246272	333686	231038
212.0	5000	2153	582	882	689	811689	246466	333980	231268
212.3	5000	2151	581	881	689	812406	246659	334274	231498
212.7	5000	2150	581	881	689	813123	246853	334567	231727
213.0	5000	2149	580	880	688	813839	247046	334861	231956
213.3	5000	2148	580	880	688	814555	247240	335154	232186
213.7	5000	2146	580	879	687	815271	247433	335447	232415
214.0	5000	2145	579	879	687	815986	247626	335740	232644
214.3	5000	2144	579	878	687	816700	247819	336033	232872
214.7	5000	2142	579	878	686	817414	248012	336325	233101
215.0	5000	2141	578	877	686	818128	248205	336617	233330
215.3	5000	2140	578	877	685	818841	248397	336909	233558
215.7	5000	2139	578	876	685	819554	248590	337201	233786

216.0	5000	2137	577	875	685	820266	248782	337493	234015
216.3	5000	2136	577	875	684	820978	248974	337785	234243
216.7	5000	2135	576	874	684	821690	249167	338076	234470
217.0	5000	2133	576	874	683	822401	249359	338367	234698
217.3	5000	2132	576	873	683	823112	249550	338658	234926
217.7	5000	2131	575	873	683	823822	249742	338949	235153
218.0	5000	2129	575	872	682	824532	249934	339240	235381
218.3	5000	2128	575	872	682	825241	250125	339531	235608
218.7	5000	2127	574	871	681	825950	250317	339821	235835
219.0	5000	2126	574	871	681	826658	250508	340111	236062
219.3	5000	2124	573	870	681	827366	250699	340401	236289
219.7	5000	2123	573	870	680	828074	250890	340691	236516
220.0	5000	2122	573	869	680	828781	251081	340981	236742
220.3	5000	2120	572	869	679	829488	251272	341270	236969
220.7	5000	2119	572	868	679	830194	251463	341559	237195
221.0	5000	2118	572	867	679	830900	251653	341848	237421
221.3	5000	2116	571	867	678	831605	251843	342137	237647
221.7	5000	2115	571	866	678	832310	252034	342426	237873
222.0	5000	2114	571	866	677	833015	252224	342715	238099
222.3	5000	2113	570	865	677	833719	252414	343003	238325
222.7	5000	2111	570	865	677	834423	252604	343291	238550
223.0	5000	2110	569	864	676	835126	252794	343579	238776
223.3	5000	2109	569	864	676	835829	252983	343867	239001
223.7	5000	2107	569	863	675	836532	253173	344155	239226
224.0	5000	2106	568	863	675	837234	253362	344443	239451
224.3	5000	2105	568	862	675	837935	253552	344730	239676
224.7	5000	2103	568	862	674	838636	253741	345017	239901
225.0	5000	2102	567	861	674	839337	253930	345304	240125
225.3	5000	2101	567	861	673	840037	254119	345591	240350
225.7	5000	2100	567	860	673	840737	254308	345877	240574
226.0	5000	2098	566	859	673	841436	254496	346164	240798
226.3	5000	2097	566	859	672	842135	254685	346450	241022
226.7	5000	2096	565	858	672	842834	254873	346736	241246
227.0	5000	2094	565	858	671	843532	255062	347022	241470
227.3	5000	2093	565	857	671	844230	255250	347308	241694
227.7	5000	2092	564	857	671	844927	255438	347593	241917
228.0	5000	2090	564	856	670	845624	255626	347879	242141
228.3	5000	2089	564	856	670	846320	255814	348164	242364
228.7	5000	2088	563	855	669	847016	256002	348449	242587
229.0	5000	2087	563	855	669	847711	256189	348734	242810
229.3	5000	2085	562	854	669	848406	256377	349018	243033
229.7	5000	2084	562	854	668	849101	256564	349303	243256
230.0	5000	2083	562	853	668	849795	256751	349587	243478
230.3	5000	2081	561	853	667	850489	256938	349871	243701
230.7	5000	2080	561	852	667	851182	257125	350155	243923
231.0	5000	2079	561	851	667	851875	257312	350439	244145
231.3	5000	2077	560	851	666	852568	257499	350723	244368
231.7	5000	2076	560	850	666	853260	257685	351006	244590
232.0	5000	2075	560	850	665	853951	257872	351289	244811
232.3	5000	2074	559	849	665	854643	258058	351573	245033
232.7	5000	2072	559	849	665	855333	258244	351855	245255
233.0	5000	2071	558	848	664	856024	258431	352138	245476
233.3	5000	2070	558	848	664	856713	258617	352421	245697
233.7	5000	2068	558	847	663	857403	258802	352703	245919
234.0	5000	2067	557	847	663	858092	258988	352985	246140
234.3	5000	2066	557	846	663	858780	259174	353267	246361
234.7	5000	2064	557	846	662	859469	259359	353549	246581
235.0	5000	2063	556	845	662	860156	259545	353831	246802
235.3	5000	2062	556	845	661	860844	259730	354112	247023

235.7	5000	2061	556	844	661	861530	259915	354394	247243
236.0	5000	2059	555	843	661	862217	260100	354675	247463
236.3	5000	2058	555	843	660	862903	260285	354956	247683
236.7	5000	2057	554	842	660	863588	260470	355237	247903
237.0	5000	2055	554	842	659	864273	260654	355517	248123
237.3	5000	2054	554	841	659	864958	260839	355798	248343
237.7	5000	2053	553	841	659	865642	261023	356078	248562
238.0	5000	2051	553	840	658	866326	261208	356358	248782
238.3	5000	2050	553	840	658	867009	261392	356638	249001
238.7	5000	2049	552	839	657	867692	261576	356918	249220
239.0	5000	2048	552	839	657	868374	261760	357197	249439
239.3	5000	2046	551	838	657	869057	261943	357477	249658
239.7	5000	2045	551	838	656	869738	262127	357756	249877
240.0	5000	2044	551	837	656	870420	262311	358035	250096
240.3	5000	2042	550	837	655	871100	262494	358314	250314
240.7	5000	2041	550	836	655	871781	262678	358592	250533
241.0	5000	2040	550	835	655	872461	262861	358871	250751
241.3	5000	2038	549	835	654	873140	263044	359149	250969
241.7	5000	2037	549	834	654	873819	263227	359427	251187
242.0	5000	2036	549	834	653	874498	263410	359705	251405
242.3	5000	2035	548	833	653	875176	263592	359983	251622
242.7	5000	2033	548	833	653	875854	263775	360261	251840
243.0	5000	2032	547	832	652	876531	263958	360538	252057
243.3	5000	2031	547	832	652	877208	264140	360815	252275
243.7	5000	2029	547	831	651	877884	264322	361093	252492
244.0	5000	2028	546	831	651	878560	264504	361369	252709
244.3	5000	2027	546	830	651	879236	264686	361646	252926
244.7	5000	2025	546	830	650	879911	264868	361923	253143
245.0	5000	2024	545	829	650	880586	265050	362199	253359
245.3	5000	2023	545	829	649	881260	265232	362475	253576
245.7	5000	2022	545	828	649	881934	265413	362751	253792
246.0	5000	2020	544	827	649	882607	265594	363027	254008
246.3	5000	2019	544	827	648	883280	265776	363303	254224
246.7	5000	2018	543	826	648	883953	265957	363578	254440
247.0	5000	2016	543	826	647	884625	266138	363854	254656
247.3	5000	2015	543	825	647	885296	266319	364129	254872
247.7	5000	2014	542	825	647	885968	266500	364404	255087
248.0	5000	2012	542	824	646	886638	266680	364679	255303
248.3	5000	2011	542	824	646	887309	266861	364953	255518
248.7	5000	2010	541	823	645	887979	267041	365228	255733
249.0	5000	2009	541	823	645	888648	267222	365502	255948
249.3	5000	2007	540	822	645	889317	267402	365776	256163
249.7	5000	2006	540	822	644	889986	267582	366050	256378
250.0	5000	2005	540	821	644	890654	267762	366324	256593
250.3	5000	2003	539	821	643	891322	267941	366597	256807
250.7	5000	2002	539	820	643	891989	268121	366871	257021
251.0	5000	2001	539	819	643	892656	268301	367144	257236
251.3	5000	1999	538	819	642	893323	268480	367417	257450
251.7	5000	1998	538	818	642	893989	268659	367690	257664
252.0	5000	1997	538	818	641	894655	268839	367963	257877
252.3	5000	1996	537	817	641	895320	269018	368235	258091
252.7	5000	1994	537	817	641	895985	269197	368507	258305
253.0	5000	1993	536	816	640	896649	269375	368779	258518
253.3	5000	1992	536	816	640	897313	269554	369051	258731
253.7	5000	1990	536	815	639	897976	269733	369323	258945
254.0	5000	1989	535	815	639	898639	269911	369595	259158
254.3	5000	1988	535	814	639	899302	270089	369866	259370
254.7	5000	1987	535	814	638	899964	270268	370137	259583
255.0	5000	1985	534	813	638	900626	270446	370408	259796

255.3	5000	1984	534	813	637	901287	270624	370679	260008
255.7	5000	1983	534	812	637	901948	270801	370950	260221
256.0	5000	1982	534	811	637	902608	270979	371221	260433
256.3	5000	1980	533	811	636	903268	271157	371491	260645
256.7	5000	1979	533	810	636	903927	271334	371761	260857
257.0	5000	1978	533	810	635	904586	271512	372031	261069
257.3	5000	1977	532	809	635	905245	271689	372301	261280
257.7	5000	1975	532	809	635	905903	271866	372571	261492
258.0	5000	1974	532	808	634	906561	272044	372840	261703
258.3	5000	1973	532	808	634	907219	272221	373109	261915
258.7	5000	1972	531	807	633	907876	272398	373378	262126
259.0	5000	1971	531	807	633	908533	272575	373647	262337
259.3	5000	1969	531	806	633	909189	272751	373916	262547
259.7	5000	1968	531	806	632	909845	272928	374185	262758
260.0	5000	1967	530	805	632	910501	273105	374453	262969
260.3	5000	1966	530	805	631	911156	273281	374721	263179
260.7	5000	1965	530	804	631	911811	273458	374989	263389
261.0	5000	1964	530	803	631	912465	273634	375257	263600
261.3	5000	1962	529	803	630	913119	273811	375525	263810
261.7	5000	1961	529	802	630	913773	273987	375793	264020
262.0	5000	1960	529	802	629	914426	274163	376060	264229
262.3	5000	1959	529	801	629	915079	274339	376327	264439
262.7	5000	1958	528	801	629	915732	274516	376594	264649
263.0	5000	1957	528	800	628	916384	274692	376861	264858
263.3	5000	1956	528	800	628	917036	274868	377127	265067
263.7	5000	1954	528	799	627	917688	275044	377394	265277
264.0	5000	1953	528	799	627	918339	275219	377660	265486
264.3	5000	1952	527	798	627	918990	275395	377926	265694
264.7	5000	1951	527	798	626	919640	275571	378192	265903
265.0	5000	1950	527	797	626	920290	275747	378458	266112
265.3	5000	1949	527	797	625	920940	275922	378723	266320
265.7	5000	1948	527	796	625	921589	276098	378989	266529
266.0	5000	1947	527	795	625	922238	276274	379254	266737
266.3	5000	1946	526	795	624	922886	276449	379519	266945
266.7	5000	1944	526	794	624	923534	276625	379784	267153
267.0	5000	1943	526	794	623	924182	276800	380048	267361
267.3	5000	1942	526	793	623	924830	276975	380313	267568
267.7	5000	1941	526	793	623	925477	277151	380577	267776
268.0	5000	1940	526	792	622	926124	277326	380841	267983
268.3	5000	1939	526	792	622	926770	277501	381105	268191
268.7	5000	1938	525	791	621	927417	277676	381369	268398
269.0	5000	1937	525	791	621	928062	277851	381632	268605
269.3	5000	1936	525	790	621	928708	278026	381896	268812
269.7	5000	1935	525	790	620	929353	278201	382159	269019
270.0	5000	1934	525	789	620	929998	278376	382422	269225
270.3	5000	1933	525	789	619	930643	278551	382685	269432
270.7	5000	1932	525	788	619	931287	278726	382948	269638
271.0	5000	1931	525	787	619	931932	278901	383210	269844
271.3	5000	1930	524	787	618	932575	279075	383472	270050
271.7	5000	1929	524	786	618	933219	279250	383734	270256
272.0	5000	1928	524	786	617	933862	279425	383996	270462
272.3	5000	1927	524	785	617	934505	279599	384258	270668
272.7	5000	1926	524	785	617	935147	279774	384520	270874
273.0	5000	1925	524	784	616	935789	279949	384781	271079
273.3	5000	1924	524	784	616	936431	280123	385042	271284
273.7	5000	1923	524	784	615	937073	280298	385303	271490
274.0	5000	1922	524	783	615	937714	280472	385564	271695
274.3	5000	1921	523	783	615	938355	280647	385825	271900
274.7	5000	1920	523	782	614	938995	280821	386086	272104

275.0	5000	1919	523	782	614	939635	280996	386346	272309
275.3	5000	1918	523	781	613	940275	281170	386607	272513
275.7	5000	1917	523	781	613	940914	281345	386867	272718
276.0	5000	1916	523	780	613	941553	281519	387127	272922
276.3	5000	1915	523	780	612	942191	281693	387387	273126
276.7	5000	1914	523	779	612	942829	281868	387646	273330
277.0	5000	1913	523	779	611	943467	282042	387906	273534
277.3	5000	1912	523	779	611	944105	282216	388165	273738
277.7	5000	1911	522	778	611	944742	282390	388424	273941
278.0	5000	1910	522	778	610	945379	282564	388684	274145
278.3	5000	1909	522	777	610	946016	282739	388943	274348
278.7	5000	1908	522	777	609	946652	282913	389201	274551
279.0	5000	1907	522	776	609	947288	283087	389460	274754
279.3	5000	1906	522	776	609	947924	283261	389719	274957
279.7	5000	1906	522	776	608	948559	283435	389977	275160
280.0	5000	1905	522	775	608	949194	283609	390236	275362
280.3	5000	1904	522	775	607	949829	283783	390494	275565
280.7	5000	1903	521	774	607	950463	283957	390752	275767
281.0	5000	1902	521	774	607	951097	284130	391010	275970
281.3	5000	1901	521	774	606	951731	284304	391268	276172
281.7	5000	1900	521	773	606	952365	284478	391526	276374
282.0	5000	1899	521	773	605	952998	284652	391783	276576
282.3	5000	1898	521	773	605	953631	284825	392041	276777
282.7	5000	1898	521	772	605	954263	284999	392298	276979
283.0	5000	1897	521	772	604	954896	285173	392556	277180
283.3	5000	1896	521	772	604	955528	285346	392813	277382
283.7	5000	1895	520	771	603	956159	285519	393070	277583
284.0	5000	1894	520	771	603	956790	285693	393327	277784
284.3	5000	1893	520	771	603	957421	285866	393584	277985
284.7	5000	1893	520	770	602	958052	286039	393841	278185
285.0	5000	1892	520	770	602	958683	286213	394098	278386
285.3	5000	1891	520	770	601	959313	286386	394354	278586
285.7	5000	1890	520	769	601	959942	286559	394611	278787
286.0	5000	1889	520	769	601	960572	286732	394867	278987
286.3	5000	1888	520	769	600	961201	286905	395123	279187
286.7	5000	1888	519	768	600	961830	287078	395379	279387
287.0	5000	1887	519	768	599	962459	287251	395635	279587
287.3	5000	1886	519	768	599	963087	287424	395891	279787
287.7	5000	1885	519	767	599	963716	287597	396147	279986
288.0	5000	1884	519	767	598	964344	287770	396402	280186
288.3	5000	1884	519	767	598	964971	287943	396658	280385
288.7	5000	1883	519	767	597	965599	288116	396913	280584
289.0	5000	1882	519	766	597	966226	288289	397169	280783
289.3	5000	1881	519	766	597	966853	288462	397424	280982
289.7	5000	1880	518	766	596	967480	288635	397679	281181
290.0	5000	1880	518	766	596	968106	288808	397935	281379
290.3	5000	1879	518	765	595	968733	288980	398190	281578
290.7	5000	1878	518	765	595	969359	289153	398445	281776
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295.0	5000	1869	517	762	590	977474	291396	401752	284342
295.3	5000	1868	517	762	589	978096	291568	402006	284539
295.7	5000	1867	516	762	589	978719	291740	402260	284735
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297.0	5000	1865	516	761	587	981206	292429	403275	285519
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299.7	5000	1860	515	760	584	986173	293803	405305	287081
300.0	5000	1859	515	760	584	986793	293975	405558	287275
300.3	5000	1858	515	760	584	987412	294146	405811	287470
300.7	5000	1858	515	760	583	988032	294318	406065	287664
301.0	5000	1857	515	759	583	988651	294489	406318	287859
301.3	5000	1857	515	759	583	989270	294661	406571	288053
301.7	5000	1856	514	759	582	989889	294832	406824	288247
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302.3	5000	1855	514	759	582	991127	295175	407331	288634
302.7	5000	1854	514	759	581	991745	295346	407584	288828
303.0	5000	1854	514	758	581	992364	295517	407836	289022
303.3	5000	1853	514	758	581	992982	295689	408089	289215
303.7	5000	1852	514	758	580	993600	295860	408342	289409
304.0	5000	1852	514	758	580	994217	296031	408595	289602
304.3	5000	1851	514	758	580	994835	296202	408847	289795
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306.3	5000	1848	513	757	578	998536	297229	410362	290952
306.7	5000	1848	513	757	578	999152	297399	410614	291145
307.0	5000	1847	513	757	578	999768	297570	410866	291337
307.3	5000	1846	513	756	577	1000384	297741	411119	291530
307.7	5000	1846	512	756	577	1001000	297912	411371	291722
308.0	5000	1845	512	756	577	1001616	298083	411623	291915
308.3	5000	1845	512	756	577	1002231	298254	411874	292107
308.7	5000	1844	512	756	577	1002846	298424	412126	292299
309.0	5000	1844	512	756	576	1003461	298595	412378	292491
309.3	5000	1843	512	755	576	1004076	298766	412630	292683
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310.0	5000	1842	512	755	576	1005305	299107	413133	293067
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311.7	5000	1840	511	754	575	1008374	299960	414390	294026
312.0	5000	1840	511	754	574	1008987	300130	414642	294217
312.3	5000	1839	511	754	574	1009600	300301	414893	294409
312.7	5000	1839	511	754	574	1010213	300471	415144	294600
313.0	5000	1838	511	754	574	1010826	300641	415395	294791
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313.7	5000	1837	511	753	574	1012050	300982	415898	295174
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314.7	5000	1836	510	753	573	1013887	301492	416651	295747
315.0	5000	1836	510	753	573	1014498	301662	416902	295938
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315.7	5000	1835	510	752	573	1015722	302001	417404	296320
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320.7	5000	1829	508	750	571	1024880	304545	421161	299178
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321.3	5000	1828	508	750	571	1026099	304884	421661	299558
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349.0	5000	1796	499	736	561	1076227	318810	442214	315208
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349.7	5000	1795	499	736	560	1077424	319142	442705	315582
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355.0	5000	1789	497	734	559	1086981	321797	446623	318565
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360.7	5000	1783	496	731	557	1097100	324608	450770	321725
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361.7	5000	1782	495	730	556	1098882	325103	451501	322281
362.0	5000	1782	495	730	556	1099476	325268	451745	322466
362.3	5000	1781	495	730	556	1100069	325433	451988	322651
362.7	5000	1781	495	730	556	1100663	325598	452231	322836
363.0	5000	1781	495	730	556	1101256	325763	452475	323021
363.3	5000	1780	495	730	556	1101849	325928	452718	323206
363.7	5000	1780	495	729	555	1102443	326093	452961	323392
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364.7	5000	1779	495	729	555	1104221	326588	453691	323946
365.0	5000	1779	495	729	555	1104814	326753	453934	324131

Curriculum Vitae

Born in P. R. China, Qinghua Jin has devoted himself on Mining Engineering technology research and development. He received his BS degree in Mineral Processing Engineering, Northeastern University, Shenyang, China (1990). From 1990 to 2000, he served as an engineer in Anshan Engineering & Research Incorporation of Metallurgical Industry (AERIMI) under the Ministry of Metallurgical Industry of P. R. China.

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