SOFTWARE APPROACH FOR THE BEST CORRELATION BETWEEN INTRINSIC PROPERTIES AND SUSCEPTIBILITY INDICES OF COAL SEAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

BY

PITOSHE SUMI

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DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA - 769008

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Under the guidance of

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National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled **"SOFTWARE APPROACH FOR THE BEST CORRELATION BETWEEN INTRINSIC PROPERTIES AND SUSCEPTIBILITY INDICES OF COAL SEAM"** submitted by **Sri Pitoshe Sumi** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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Date:

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ABSTRACT

Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. Correlation analysis measures the degree to which changes in one variable are related with changes in another. A proper assessment of the best correlation of coal needs to be done so that mine operators are notified well about the classification and spontaneous heating susceptibility of coal in advance. Therefore, the determination of the best correlation of coal between the intrinsic properties and susceptibility indices of coals to spontaneous heating is essential for a better classification. A user friendly application has been made which records the various parameters of the coal which have been determined by proximate analysis, the ultimate analysis and the petrographic analysis, they were all correlated with the susceptibility indices of coal. After the correlation it generates the best correlation coefficient between the various parameters of susceptibility indices and intrinsic. The susceptibility indices are taken as dependent variables and each constituent obtained from the proximate, ultimate and petrographic analyses as an independent variable. The main aim of this analysis is to investigate the relation between the susceptibility indices and the intrinsic properties and their variations in correlation and generate the best correlation. The data inputs are entered according to the mining conditions for determining the best results of correlation. This software is useful in advance to know the best correlation between intrinsic properties and susceptibility indices which will be helpful to know the classification of coal.

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Chapter 1

INTRODUCTION

INTRODUCTION

1.1 GENERAL

When coal is exposed to air, oxygen is absorbed and some portions of the coal substance with production of some gases (mainly CO, CO_2) and water vapour along with the evolution of some amount of heat. The rate of oxidation of coal at ambient temperature gives a measure of the proneness of coal to auto oxidation. This process of self-heating of coal or other carbonaceous material resulting eventually in its ignition is termed as “spontaneous heating” or “auto oxidation”. The occurrences of fires in coal mines are mostly due to spontaneous combustion of coal. It subsidizes to problems such as loss of coal reserves due to burning, creates environmental pollution and unfavorably affects the safety and economic aspects of mining. A number of approaches have been made by different researchers for categorizing coals based on their intrinsic properties such as volatile matter, fixed carbon, ash, moisture, total moisture, total iron, non-pyretic iron, total sulphur contents of coal (Pal, 1994). A few researchers tried to make use of petrographic classification, but have not been found to be enough for practically utility in distinguishing the reliability of coal to spontaneous heating. A number of approaches have been developed over the years to assess the proneness of coal to spontaneous heating.

Correlation is used to describe the linear relationship between two or more continuous variables. It measures the strength and direction of the linear relationship between two or more variables. These correlated variables may have a strong relation or a weak relation. Not always there is a cause and effect relationship between the variables when there is a change; that might be due to uncertain change [12].

Although lot of research has been done on the subject, a proper assessment of the best correlation of coal needs to be done so that mine operators are notified well about the classification and spontaneous heating susceptibility of coal in advance. Therefore, the determination of the best correlation of coal between the intrinsic properties and susceptibility indices of coals to spontaneous heating is essential for a better classification.

Correlation is a technique for studying the relationship between two quantitative, continuous variables**.** The correlation coefficient, r, can take a range of values from +1 to -1. There is no relationship between the two variables if it gives a value of 0. A value greater than 0 indicates a positive relationship, that is, as the value of one variable increases so does the value of the other variable. A value less than 0 indicates a negative relationship, that is, as the value of one variable increases the value of the other variable decreases. The closer the correlation coefficient the stronger is the relationship between the two variables the. ‘r’ will range to either +1 or -1 depending on whether the relationship is positive or negative, respectively. The closer the value of r to 0 the greater the variation around the line of best fit. Correlation only establishes the strength of the association between two variables [13].

1.1 OBJECTIVE

The aim of the project is to develop software for the best correlation between the various intrinsic properties and susceptibility indices of coal in order to find out the properties that influence spontaneous heating propensity of coal.

The purpose of correlation analysis is to measure and interpret the strength of a linear or nonlinear relationship between two continuous variables i.e. between the Susceptibility indices and intrinsic properties.

Chapter 2

LITERATURE REVIEW

LITERATURE REVIEW

2.1 SPONTANEOUS HEATING OF COAL

Low-temperature oxidation of coal is the primary source of heat leading to uncontrolled and mainly undesired changes in thermal properties and under favorable conditions, to spontaneous combustion, which in turn can result in destruction and financial losses. Spontaneous combustion in a coal seam occurs when the quantity of heat generated by the oxidation of organic matter is greater than the quantity of heat degenerate (Banerjee at el, 1972). Though oxidative heat generation is the principal reason extraneous factors or conditions do play a significant role. The rate heat generation and accumulation, is influenced by certain genetic and physical parameters; that is, rank, thermal conductivity, ambient temperature and size of coal particles. An increase in rank (associated with decreased porosity, internal surface area, volatile matter and moisture contents) retards the passage of oxygen to the combative sites. A low rank coal is therefore more prone to self-heating.

Spontaneous combustion leading to open fire:

Spontaneous combustion is the most prevalent source of ignition of firedamp. Many theories have been advanced to explain spontaneous combustion phenomena. Most widely accepted theory is the ‘coal-oxygen complex’ formation. According to this theory, freshly exposed coal has high affinity to oxygen. At first, oxygen is adsorbed by the purely physical process. It is followed by a chemical chain reaction resulting in oxidation of certain constituents – mainly, methylene and methyl groups – in coal**.**

Coal + oxygen → coal-oxygen complex

→ oxidized coal + CO, CO_2, water vapour + heat.

The developed heat increases coal temperature. At high temperature, oxygen affinity of coal increases further. Thus, the chain reaction continues until the temperature reaches the ignition point of coal when it catches fire**.** Ideal condition for spontaneous combustion to take place is the availability of oxygen but ventilation is negligibly small to dissipate the generated heat. Loose and fractured coal will be the ideal place to onset spontaneous combustion. The developing fires i.e. fires in goafs, old workings, and fractured coal pillars are very common in coal mines. Such heating's are difficult to be detected at early stages and hence, most of the times, measures cannot be taken to control them at early stages. Hence they eventually may lead to ignition temperature of coal and blazing fire. When the developing fires travel up to open mine workings such as roadways / coal faces / shaft, visibly active combustion takes place characterized by high flame. The fire with blazing flame quickly spreads in the direction of ventilation current. If appropriate steps are not adopted within a few hours, the open fires will assume shattering dimension (Ramlu, 2007).

2.2 MECHANISM OF SPONTANEOUS HEATING

The auto oxidation of coal is a complex physico-chemical process which is accompanied by the concentration of oxygen, formation of coal-oxygen complexes and their decomposition leading to the discharge of heat. This complexivity of the process is enormous because of the great diversity in the coal substance with the associated mineral matter and the conditions of oxidation. During the oxidation of the heterogeneous mass, concurrent and overlapping reactions take place which are very difficult to separate out. The rate of oxidation at ambient temperature gives a measure of the proneness of coal to auto-oxidation. A large number of stable chemical chain reaction takes place due to several oxidation states of carbon and a variety of strong carbon oxygen bonds are formed. The observable elemental, compositional and structural changes reveal that the reaction of oxygen with solid coal is a time dependent dynamic process. Observable changes in coal molecular structure and composition arise from prolonged sequence of events whose components reveals complex inter-relationships. Thus the reaction environment is heterogeneous intrinsically because two bulk phases, solid and gas are present and extrinsically because diverse structural changes prompted by the reaction, affect the overall coal reactivity (Pal, 1994).

Porous solid absorbs the liquids or gases or the solution of gas/liquid, which is known as absorption. When accumulation restricts at the surface liberating heat and rate of penetration is negligible then it is considered as adsorption but if uniform penetration in the bulk of the solid occurs, then it is called absorption. The absorptions is always an endothermic phenomenon and starts from the surface of the solid and consumes heat of the solid for penetration. The energy at the surface always decreases. The process where physical forces like inter-molecular attraction are responsible, are known as physical adsorption or Van der Wall's adsorption, but when active force needs to break the chemical nature of the compound is called chemisorption or activated adsorption. Coal gets heated up on absorbing oxygen, whose decomposition phenomenon can be expressed in the following manner. Oxidation is very slow below 50^{o}C and accelerates above 50^{o}C, but above 80^{o}C, a period of steady state is maintained, probably due to the removal of moisture of coal. The removal of oxides of carbon begins from 120^oC. The collaboration of oxygen with coal accelerates rapidly up to 180^oC and thermal decomposition starts between 180^oC to 220^oC. Self-sustained process of combustion begins in between 220^oC to 275^oC with very rapid rise of temperature until the ignition point is attained (Sahu et al. 2009).

2.3 INTRINSIC PROPERTIES OF COAL

- **Proximate analysis** (IS 1350 Part I -1984)

  The aim of coal proximate analysis is to determine the amount of fixed carbon (FC), volatile matters (VM), moisture, and ash within the coal sample. The variables are measured in weight percent (wt. %) and are calculated in several different bases.
- **Ultimate analysis** (IS 1351 - 1959)

  The objective of coal ultimate analysis is to determine the basic chemical elements present in the coal. The ultimate analysis determines the amount of carbon (C), hydrogen (H), oxygen (O), sulfur (S), and other elements within the coal sample.
- **Petrographic analysis** (IS 9127 Part II - 1992)

  Coal is a rock composed of number of distinctive organic entities called macerals and lesser known amounts of inorganic substance called as minerals. Each maceral has a distinct set of property and it effects the behavior of coal. Coal surface can be analyzed at macroscopic level and microscopic level. At macroscopic level coal appears as banded or non-banded rock. The bands are divided into four major litho types – Vitrain, Clarain, Durain, and Fusain. At microscopic level coal has three basic groups of macerals and mineral matter. The macerals are of three types – Vitrinite, Liptinite and Inertinite.
- **Calorific value** (IS 1350 – 1997)

  The calorific value or heat of combustion or heating value of a sample of fuel is defined as the amount of heat developed when a unit weight (or volume in the case of a sample of gaseous fuels) of the fuel is completely burnt and the products of combustion cooled to a standard temperature of 298 ^0K.

2.4 EXPERIMENTAL STUDIES FOR SUSCEPTIBILITY INDICES OF COAL

In the past, a number of researchers have attempted to assess the spontaneous heating affinity of coal by carrying out different experiments in the laboratory and different countries of the world follow different methods for this purpose. It has also been observed that some of these methods are time consuming, monotonous and do not give reproducible results. Various experimental techniques are described in the following sections:

- **Ignition Point Temperature (Flammability Temperature) Method:**

  It is the minimum temperature at which the coal begins to ignite. Ignition point temperature method is based on the fact that the ignition temperature of a coal decreases with increasing oxidation of coal and the difference between the ignition temperature of coal before and after oxidation can be used as a measure of liability of the coal to spontaneous combustion. It depends on the rank of coal, nature and intensity of ignition source, particle size, moisture, ash content and oxygen concentration (Nimaje et al., 2010).

- **Crossing point temperature:**

  The lowest temperature at which the exothermic reaction in the coal bed can be pragmatic to be self-propelled under the experimental conditions is termed as the crossing point of the coal concerned. This method foresees heating coal samples in the oxidizing atmosphere at a definitely programmed rate of temperature rise. Coals which are highly susceptible to spontaneous heating would have lower values of crossing point temperature and poorly susceptible coals have relatively high values (Mahdevan et al., 1985).

- **Olpinski Index Method:**

  In this method, liquid quinoline is heated in an electric oven to boil gently at a temperature of 230^0C producing quinoline vapour. The coal samples are powdered and small pellets of 1g of -72 mesh are developed out of these powdered samples. These pellets are heated in directly by quinoline vapour in an atmosphere of oxygen which is made to flow over the coal pellet at predetermined rate. While heating the coal pellets, a thermocouple is inserted into it and output of the thermocouple is given To a temperature recording system. The temperature versus time plot of the coal samples is directly obtained by this instrument. The rate of rise of temperature at the moment of equalization of supplied oxygen gas and coal pellet temperature is either graphically determined by drawing tangent to the curve at the point corresponding to the quinoline vapour temperature at 230^{0}C. The rate of rise of temperature found in this way is expressed in ^{0}C/min is an indication of spontaneous heating susceptibility of the coal. (Karmakar et al., 1989). This index is known as Olpinski index and is denoted by Sz_a. In this method Sz_a index is corrected for ash content of the coal and is expressed as Sz_b which is as given below:

$$Sz_b = \frac{Sz_a}{100 - A} \times 100$$

Where, Sz_b– Spontaneous heating index free of ash

A – Ash content of coal expressed in %.

The increase of Sz_b index indicates that the sample is more susceptible to spontaneous combustion.

- **Wet oxidation method:**

  An indirect method of measuring the oxidisiability of coals by collaboration of coal with oxidants like H_2O_2, $KMnO_4$, Br_2 etc., have also been tried in some countries. The oxidation of coal is a three stage process. They are: stepwise oxidation of coal leading to immediate formation of surface oxides of easily oxidisable species, followed by the formation of colloidal humic acids and finally to small aromatic and aliphatic acids in an alkaline medium. It has been found that alkaline permanganate oxidation of different coals produces carbonic, acetic, oxalic and many benzene carboxylic acids (Tarafdar et al., 1989 and Panigrahi et al., 1996). It is a quick method of categorization of coal oxidation.

2.5 NATIONAL AND INTERNATIONAL STATUS

National status:

Bhattacharya (1971) carried out laboratory experiments to evaluate the rates of heat produced from different coals by a calorimeter during sorption of water vapour in isothermal conditions. It was discovered that the rate of heat generation in a particular coal increases with the equilibrium humidity deficiency of the coal, i.e. with the difference of equilibrium humidity of air and coal. For a given coal, the rate of heat generation due to oxidation has been detected to be negligible in comparison with that due to sorption of water vapour. The results also show that under a given test condition the characteristic rate of heat production is dependent on the type of coal, its particle size and its weathering.

Banerjee (1972) determined the Crossing Point Temperature (CPT) of a number of Indian coal samples following the Crossing Point Temperature method. He conveyed that coals with crossing points temperatures between 120^0C & 140^0C could be considered to be highly susceptible to spontaneous heating and those above 160^0C are poorly susceptible. The moderately susceptible ones depicted values in between the above mentioned.

Nandy et al. (1972) mentioned the deviation in Crossing Point Temperature values with the volatile matter, oxygen percentage and the moisture content of coal. He got that CPT normally decreases with the increase in each of these constituents of coals. But beyond 35% V.M. 9% oxygen, or 4 to 6% moisture content there is not much change in CPT values. In fact, above 4 to 6% moisture content in coal (on as received basis), the CPT values reveals a rising trend.

Singh et al. (1984) outlined the present techniques of assessment of spontaneous combustion risk indices for sorting coal seams liable to self-heating. Factors affecting liability of coal to spontaneous combustion depend upon intrinsic factors as well as external factors promoting the self-heating. An adiabatic oxidation test was explained which can be used to assess the liability of coal according to intrinsic reactivity. Systems of risk classifications are based on the synthesis of ratings assigned to intrinsic as well as extrinsic factors. Precautionary measures to assure spontaneous combustion hazard in underground long wall mining, stockpiling and seaborne transport of coal are reported together with the techniques of fire fighting by the use of liquid nitrogen.

Tarafdar and Guha (1989) carried out a preliminary investigation using wet oxidation method in 1989 and they reported that a systematic and thorough study along this line is required as the significance of this technique.

Chandra et al. (1990) carried on a preliminary survey of the frequency of occurrence of fire due to spontaneous combustion in the various seams of the Raniganj Coalfield and showed the 14 possibility of a relationship between coalification and spontaneous combustion of coals. Besides rank, as manifested from reflectance studies, the amount of vitrinite and exinite contents of the coal seams also determined the spontaneous combustibility of the coal seams. The found that pyrite of the Raniganj Coalfield had no influence on the combustibility of the coal seams. It was revealed that the proneness to spontaneous combustion of the coals is related to coalification. As the coalification increases, the intensity of spontaneous combustibility decrements gradually from highly susceptible to moderately susceptible to least susceptible to the spontaneous combustion stage.

Panigrahi et al. (1997) performed experiments for the determination of Russian U-index, 10 samples from Jharia coalfields have been examined using this method. The carbon, hydrogen, nitrogen and sulphur contents for this samples have been determined by using Fenton's method of ultimate analysis, in addition to this, the crossing point temperature of these samples have also been determined. Then, attempts have been made to correlate the Russian index and CPT of coal samples with its basic constituent's viz. carbon, hydrogen and ash content's. It has also been observed that from point of susceptibility of spontaneous heating, Russian index shows similar relation with the basic constituents of as the crossing point temperature, which may prove to the handy method of coal categorization in Indian context.

Panigrahi et al. (2004) carried out extensive field studies to look into the pillar fire problems in one coal mine in India. A Thermal IR gun and a Thermo vision camera have been applied for thermal scanning to assess the state of heating in selected pillars. Special sampling setups have been planned to collect gas samples from the holes drilled into the selected pillars and the multi gas detector is used to analyse the composition of samples in situ. In order to anticipated the spontaneous heating in coal pillars, different gas ratios have been calculated and it has been observed that some of the established gas ratios, viz. Graham's ratio, Young's ratio etc. have resulted in negative values in samples containing high amounts of methane. The modified gas ratios have been aimed which will be useful for predicting the pillar fires. These ratios may also be used for evaluating the condition of fires in sealed-off areas.

Sahay et al. (2008) proposed realistic characterization of coal towards spontaneous heating for taking appropriate measures. They developed a methodology based on thermo-de compositional study of coal sample for finding of minimum temperature at which coal bed temperature starts self-propellant known as critical temperature and a new liability index based on it. They presented a brief description of different liability index specially based on thermal study, a critical analysis of dependency of vital temperature on moisture content, ash content, volatile matter, carbon content, surface area and porosity, new liability index based on thermo de compositional study of coal sample and correlation with liability index model based on coal close analysis results of coal sample including surface area and porosity.

Nimaje et al. (2010) made thermal studies on spontaneous heating of coal. Of all the experimental techniques developed thermal studies play crucial and dominant role in evaluating spontaneous heating susceptibility of coal. They created an overview of thermal studies carried out by many researchers across the globe for finding of spontaneous heating of coal and reported that lot of stress on experimental techniques is necessary for evolving appropriate strategies and effective plans in advance to retard occurrence and spreading of fire.

International status:

Feng et al. (1973) discovered a composite liability index using the results of Crossing Point Temperature experiments, called FCC index. This is calculated using the following equation.

$$\text{Liability index} = \frac{\text{Average heating between 110 C and 220 C}}{\text{Relative investigation temperature}} * 10$$

Peter et al. (1978) reported the oxidation of the weathered substances has an apparent activation energy lying between 63.9 and 69.0 kJ/mole which are independent of their moisture content. However, the rate of oxidation of char raises with increasing moisture content and decreases with increasing carbonization temperature of the parent coal, and with the extent of the char's weathering.

Gouws et al. (1989) designed an adiabatic calorimeter to enable the spontaneous combustion propensity of coal to be set up. Various indicators of self-heating potential, such as total temperature rise, starting rate of heating, minimal self-heating temperature, and kinetic constants were investigated. Results obtained from the adiabatic tests were compared with the results of crossing-point temperature findings and various thermal analysis (DTA) tests for the same coals, with a view to formulating a mathematically consistent spontaneous combustion liability index. This paper summarises the major components of the adiabatic calorimeter.

Smith at el. (1994) designed and developed the sponcom program in the U.S Bureau of Mines to aid safety in the assessments of the spontaneous combustion risk of an underground mining operation. It uses the available information to make decisions based on a series of rules provided by the programmer

Anthony et al. (1995) said that self-heating of coal mainly takes exothermic reactions of oxygen at reactive radical sites within the coal and the enhancing or controlling effect that water had on these reactions. The thermal reaction of samples of low-rank coals, dehydrated by heating under nitrogen flow at 105°C and revealed to dry oxygen, is similar to or slightly less than that observed when they are flow-dried at 30°C and tightly bound moisture remains. The most likely reason is that moisture impacts the nature of the radical sites where oxidation occurs. By blocking the formation of stabilized radicals, it promotes faster oxidation which may lead to enhanced thermal response, although some of the extra heat may be taken up by the residual moisture. When loosely bound moisture is granted to remain in the coal, the thermal response on exposure to dry oxygen decreases very quickly, due mainly to blocked access to responsive sites and dissipation of heat brought forth by any oxidation that does occur. The effect of action is comparatively minor and the course of the oxidation reaction responsible for generating heat does not looks to be changed by the presence of small amounts of loosely bound moisture.

Ren et al. (1998) used adiabatic calorimeter for the propensity of 18 pulverised coals (Australia, UK, US, Indonesia, South Africa, South America) to spontaneous combustion. All The coal samples were tested at a starting temperature of 40°C and three samples at 60°C. Their propensities to spontaneous combustion were ranked to their initial rate of heating (IRH) and total temperature rise (TTR) values. The results presents that, air humidity is an important factor is determined whether a heating will move on rapidly or not. The particle size dispersion of the coal affects the IRH and TTR values, with comparatively smaller particles inclined to be more reactive. Aged and pre-oxidised coals have higher IRH and lower TTR values, and the coal becomes less reactive. The magnitude of the temperature raises (TTR) with increasing starting temperature.

Kaymakci and Didari (2002) carried out linear and multiple regression analysis to determine the relationship between spontaneous combustion parameters (derived from time temperature curves found from laboratory tests) and coal parameters (obtained from proximate, ultimate and petrographic analysis) have been explained. The additive regression analysis have shown that ash (A), volatile matter (VM), carbon (C), hydrogen (H), exinite (E), inertinite (I) and mineral matter (MM) are the main factors impacting spontaneous combustion. According to the multiple regression analysis, these major factors are volatile matter, carbon, hydrogen, nitrogen (N), oxygen (O), sulphur (S) and inertinite. They have gained some empirical equations using statistical models.

Edwin (2007) introduced the Objective Fitness Correlation, a new tool to analyse the evaluation accuracy of coevolutionary algorithms. The correlation between the objective fitness and the subjective fitness used in a coevolutionary algorithm yields the Objective Fitness Correlation. The OFC measure is applied to three coevolutionary evaluation methods. A high OFC is found to correspond to periods where the algorithm is able to increase the objective quality of individuals.

Nelson et al. (2007) used a large variety of methods to earn insight into the processes that govern the self-heating of coal. These include oxidation mechanisms, ranking the propensity of various kinds of coals to self-heat, and the catching and suppression of self-heating. Moist coal in coal mines and stockpiles have very different combustion characteristics than those predicted on the basis of dry testing. Consequently, methods for ranking the propensity of coal to spontaneously burn in literal mining conditions require to be enhanced.

Daiyong et al. (2007) assumed that spontaneous combustion of coal seams is a complicated process that is a function of the interplay of internal and external conditions. Based on geologic field investigations and understandable analysis, four models of spontaneous combustion for coal were build up: A genesis-type model, a coal-fires propagation model, a model for the liberal stages and products of a coal fire and a cross-sectional model of zones.

Andre at el. (2009) conducted an experimental study to assess the correlation between the subjective sense of nasal patency and the outcomes found with rhinomanometry and acoustic rhinometry in which correlations were sought between subjective nasal patency symptoms and objective scores as found with rhinomanometry [nasal airway resistance (NAR)] and acoustic rhinometry [minimal cross sectional area (MCA)]. Correlations were related to unilateral or combined assessment of nasal passages and to symptomatic nasal obstruction or unobstructed nasal breathing. The correlation between the outcomes found with rhinomanometry and acoustic rhinometry and an individual’s subjective sensation of nasal patency remains uncertain.

2.6 STUDY OF CORRELATION

The correlation measures the strength of the linear relationship between numerical variables. Here the goal is to use one variable to predict another and show the strength of the linear relationship that exists between the two variables. The most common correlation coefficient is the Product Moment correlation coefficient, better known as Pearson's 'r'. Pearson's 'r' is used to determine the correlation between two variables under three conditions [14]. First, both variables must be interval or ratio measures second the relationship between the two variables must be linear. The third condition is that both variables are normally distributed.

Correlation coefficient:

The strength of linear association between two numerical variables is determined by the correlation coefficient 'r' correlation coefficient can also be calculated by

$$r = \frac{\sum_{i=1}^{n} (X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \overline{X})^2 \sum_{i=1}^{n} (Y_i - \overline{Y})^2}},$$

A positive coefficient indicates that two variables X and Y systematically vary in the same direction: as one variable increases, the other variable increases. The closer the coefficient is to +1.00, the stronger the positive relationship. A negative coefficient indicates that two variables systematically vary in opposite directions: as one variable increases, the other variable tends to decrease. The closer the coefficient is to -1.00, the stronger the negative relationship. A coefficient close to zero indicates that no systematic co-varying exists between the variables. There are several important correlation measures. They vary according to the data types of the variables. The graphs below show different correlations [10].

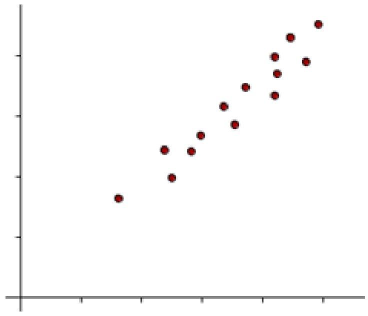

Fig 2.1: Strong positive correlation [10]

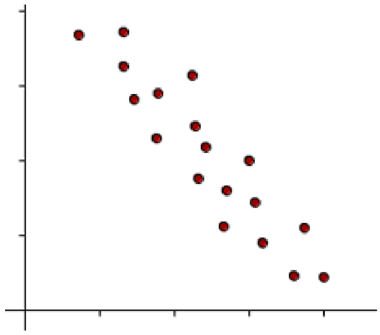

Fig 2.2: Strong negative correlation [10]

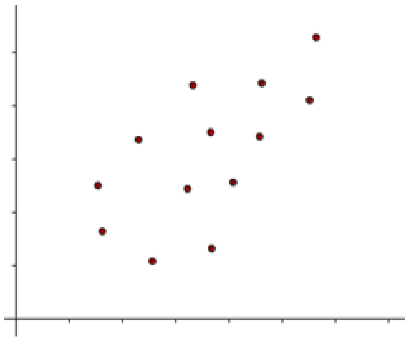

Fig 2.3: Weak correlation [10]

Properties of Correlations

- The value of correlation ranges from –1 and 1:
  - r is a dimensionless quantity; that is, r is independent of the units of measurement of X and Y.
  - If the correlation is more than 0, then as X increases Y increases, the two variables are said to be positively correlated. r = 1 indicates a perfect positive correlation.
  - If the correlation is less than 0, then as X increases Y decreases, the two variables are said to be negatively correlated. r = -1 indicates a perfect negative correlation.
  - If the correlation is 0 then there is no relationship between X and Y. Than the two variables are said to be uncorrelated.
- The correlation coefficient is a measure of the strength of the linear trend relative to the variability of the data around that trend. Thus, it is dependent both on the magnitude of the trend and the magnitude of the variability in the data (Yount, 2006).

Point Biserial Coefficient

The point biserial correlation coefficient is computed between one interval or ratio variable and one dichotomous variable. The term "biserial" refers to the fact that there are two groups of persons (X= 0.1) being observed on the continuous variable (Y) (Yount, 2006).

Kendall's Coefficient of Concordance (W)

Kendall's W extends Spearman Rho to more than two groups. This procedure is beneficial for studies in which three or more groups generate rankings of items. The resulting statistic represents the level of agreement among the groups in ranking the items. The Kendall's W is used to measure the degree of agreement exists among the groups regarding the relative importance of the stated competencies (Yount, 2006).

Coefficient of Determination (r^2)

The strength of affiliation or degree of closeness of the relationship between two variables is measured by a relative value. The coefficient of determination, r^2, is the square of the Pearson correlation coefficient. The coefficient of determination is the proportion of the difference that is shared by the variables. It is sometimes expressed as a percentage when we discuss the proportion of variance explained by the correlation (Yount, 2006).

Interpretation of Correlation Coefficient

The sign of the correlation coefficient (i.e. positive or negative) defines the relationship how weakly or strongly they are correlated. The absolute value indicates the strength of the correlation [10].

- -1.0 to-0.7 strong negative relationships.
- -0.7 to-0.3 weak negative relationships.
- -0.3 to +0.3 little or no relationships.
- +0.3 to +0.7 weak positive relationships.
- +0.7 to +1.0 strong positive relationships.

Chapter 3

DEVELOPMENT OF SOFTWARE

3.1 SOFTWARE REVIEWS

The Microsoft Excel 2010 is used for the development of the program, in which the correlation is done and the data’s were saved in a spreadsheet.

Microsoft Excel:

It has assembly of statistical functions which brings ease for calculating statistical data quickly. Amongst Stats function, finding correlation manually between two given datasets can be unwieldy, but with intrinsic Excel **CORREL** function, finding co-relation coefficient is a breeze. The Correlation values ranges from –1.0 to +1.0, implying +1.0 as best co-relation between datasets and conversely is the case with –1.0 [9].

The syntax used for Correlation Coefficient= **CORREL (array1, array2)**

Visual Basic for Applications (VBA):

It is an implementation of Microsoft's event-driven programming language Visual Basic and its associated incorporated development environment (IDE), which are built into most Microsoft Office applications. VBA enables building user functions, automating processes and retrieving Windows API (Application Programming Interface) and other low-level functionality through dynamic-link libraries (DLLs).

VBA is closely linked to Visual Basic and uses the Visual Basic Runtime Library, but the code is run within a host application rather than as a standalone program. However, it can be used to control one application from another via OLE (Object Linking and Embedding) Automation. Using VBA, most of the security features lie in the hands of the user, not the author. The user who runs any document containing VBA macros can preset the software with user preferences. The users can protect themselves from outbreak by disabling macros from running in an application, or only grant permission for a document to run VBA code if they are sure the source of the document can be trusted [9].

3.2 PROGRAM STRUCTURE

For initial database, each correlation between susceptibility indices and intrinsic properties will be registered in excel as database. The total sample correlation will be preferred when both total sample and subgroup correlations were provided. The program determines the best correlation between them. The application was written in VBA language which can be used in all Excel versions. The program provides a better user interface with user friendly functions, the application consist of user details, user operation, evaluating interface and the database. The user may enter the data according to the parameter or information collected from the colliery. This program is accomplished through the user interactive data input screens that prompt the user for the information. During the input process the screens are expanded and the data's are entered.

Software approach

First of all the user form is opened as the workbook is run. The program uses a series of interactive data input screens for better interface.

Flowchart:

A proper demonstration of the program analysis has been shown in the flowchart below (Plate 3.1)

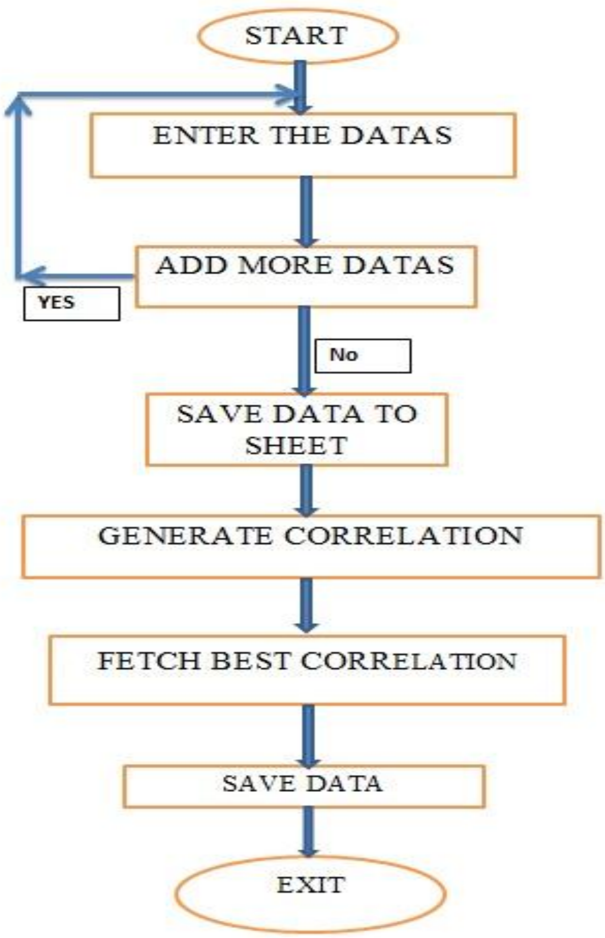

Plate 3.1: Flowchart of the program

The first page consists of user details which shows the details of coal sample. (Plate 3.2)

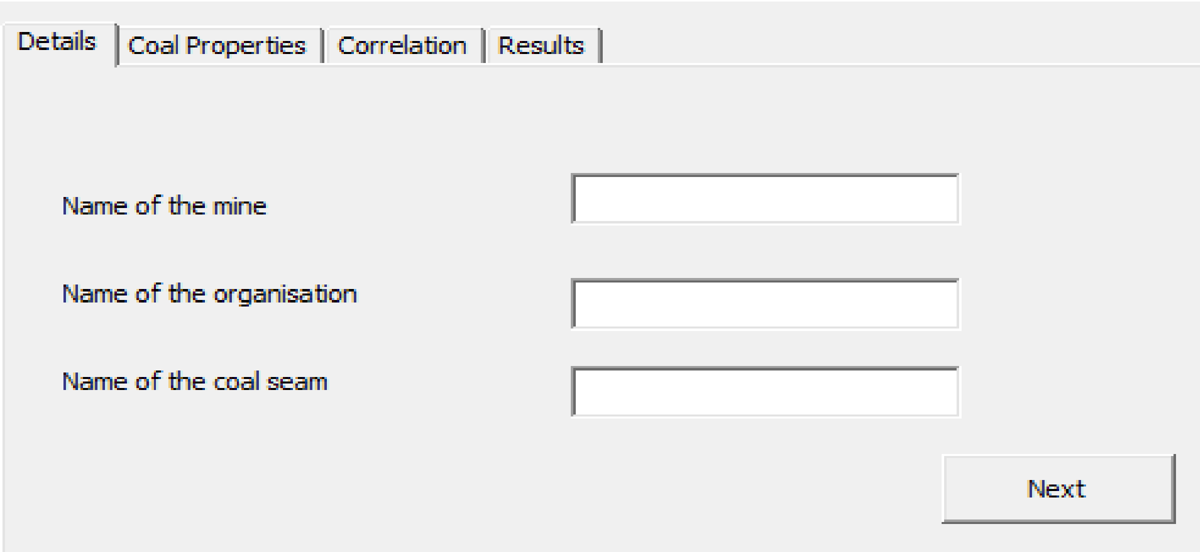

Plate 3.2: Image shows the details of coal

Screens are expanded to provide specific information for data entries which is saved in the sheet. The second page consists of coal properties, where all the parameters of various experimental results were entered. (Plate 3.3)

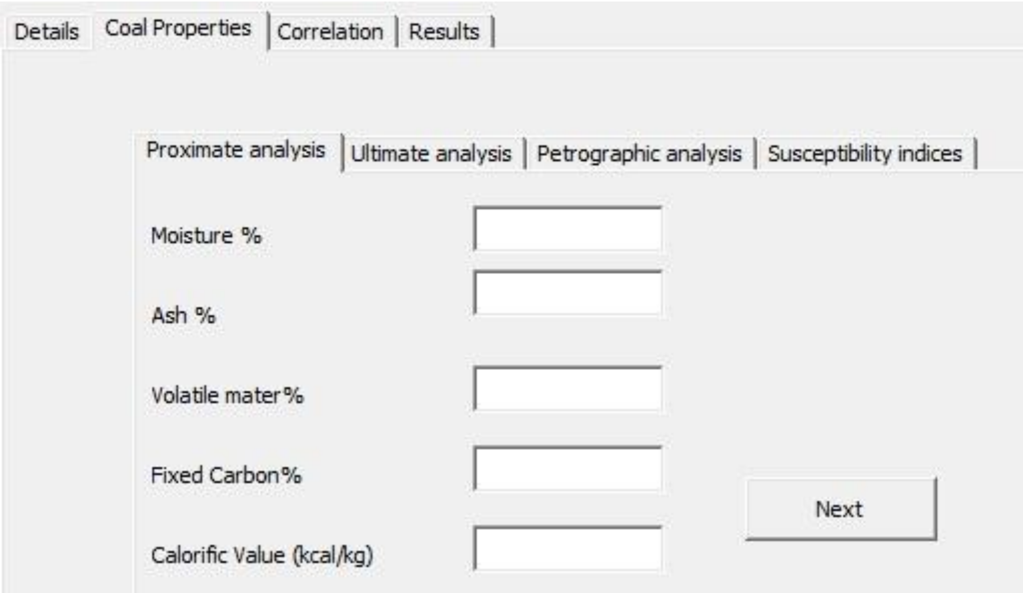

Plate 3.3: Image shows the properties of coal

In this form, the correlation between the different parameters are generated and saved to the sheet in excel. (Plate 3.4)

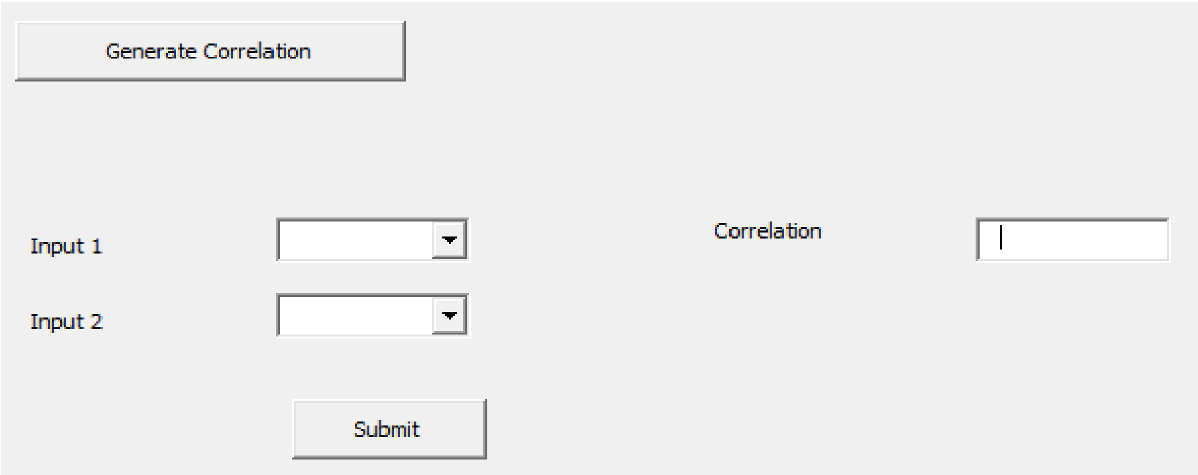

Plate 3.4: Image shows the correlation generation

The fetching of the best correlation is calculated by Excel, where the different inputs along with their correlation are determined (Plate 3.5)

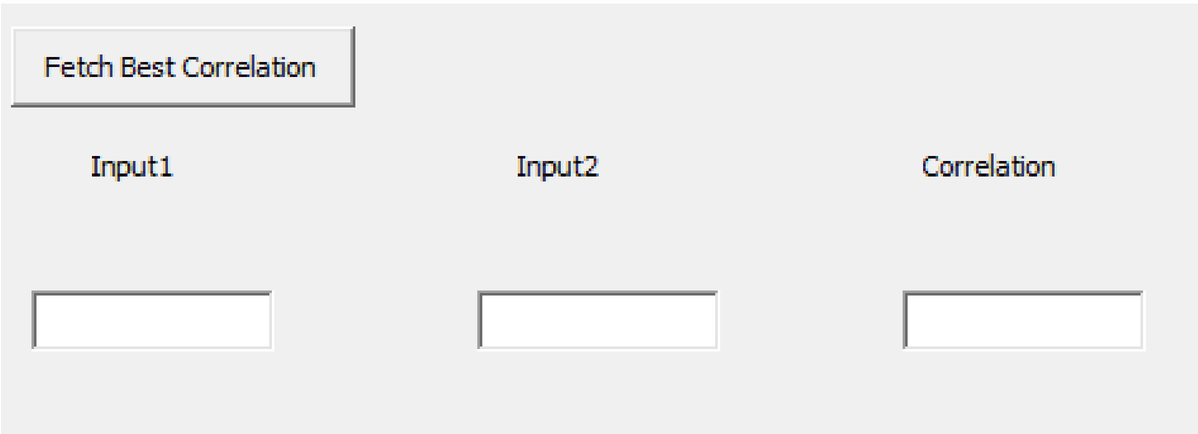

Plate 3.5: Image shows the best correlation

The program output gives the best correlation between the susceptibility indices and intrinsic properties and also the correlation between the parameters.

3.3 PROGRAM ANALYSIS

The data's from some of the literature were entered and the best correlation was fetched between the intrinsic properties and susceptibility indices. The best correlation results of the program were compared with the literature results.

Correlation analysis between susceptibility indices and intrinsic properties:

The susceptibility of coal to spontaneous combustion is influenced by the intrinsic properties. Therefore, correlation studies were carried out between the different susceptibility indices and the coal characteristics as obtained from proximate, ultimate and petrographic analysis. The susceptibility indices are taken as dependent variables and each constituent obtained from the proximate, ultimate and petrographic analysis as an independent variable. Correlation coefficients between different susceptibility indices and constituents obtained from proximate, ultimate and petrographic analysis were used for determining the best correlation.

The following nomenclatures have been used in the correlation study:

r = Correlation coefficient

M= Moisture content %

VM= Volatile Matter content %

A = Ash content %

CV= Calorific Value (kcal/kg)

C= Carbon content %

H= Hydrogen content %

O= Oxygen content %

N= Nitrogen content %

S= Sulphur content %

V= Vitrinite content

L= Liptinite content

I= Inertinite content

CPT= Crossing point temperature (^{0}C)

Sz_b= Olpinski Index (^{0}C/min)

FT= Flammability temperature (^{0}C)

EMF = Wet oxidation potential difference (mV)

Chapter 4

DISCUSSION AND CONCLUSION

DISCUSSION AND CONCLUSION

4.1 DISCUSSION

This application is a new analytical tool which can be used for the study of correlations. The current work is restricted to test problems, and calculation of the correlation may be possible for unlimited set parameters for test problems. For the determination of correlation the two variables can be measured in entirely different units. Indeed, the calculations for Pearson's correlation coefficient were designed such that the units of measurement do not affect the calculation - this allows the correlation coefficient to be comparable and not influenced by the units of the variables used. To develop the program data's were gathered from different journals and papers which have been published. They were compared and correlated with the application to form the knowledge base for the program. The prediction of spontaneous heating susceptibility of coal is determined by the value of their coefficient. The best correlation between intrinsic properties and susceptibility indices can be used for prediction of spontaneous heating of coal which will be used for the classification of coal.

4.2 CONCLUSION

This application determines the correlation between the susceptibility indices and intrinsic properties of coal as a set of individuals. A very good correlation coefficient indicates that the parameters can be used to predict the spontaneous heating susceptibility of coal, if the correlation is generally weak, it is not a good parameter for the prediction of the spontaneous heating susceptibility of coal, so one must be cautious about relying on those parameters however, with a strong and reproducible correlation, correlation tests could play a role in measuring the effect of Spontaneous heating of coal. The main contribution is the introduction of a new software tool for the study of correlation. This approach can provide valuable information about the behaviour of best correlation between different coal properties and susceptibility indices, and this best correlation will be used to the development of new software for the classification of coal.

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