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NORBERT SKOCZYLAS*

ESTIMATING GAS AND ROCK OUTBURST RISK ON THE BASIS OF KNOWLEDGE AND EXPERIENCE – THE EXPERT SYSTEM BASED ON FUZZY LOGIC

OCENA STANU ZAGROŻENIA WYRZUTOWEGO NA PODSTAWIE WIEDZY I DOŚWIADCZENIA EKSPERTÓW – SYSTEM EKSPERCKI NA BAZIE LOGIKI ROZMYTEJ

The Author endeavored to consult some of the Polish experts who deal with assessing and preventing outburst hazards as to their knowledge and experience. On the basis of this knowledge, an expert system, based on fuzzy logic, was created. The system allows automatic assessment of outburst hazard. The work was completed in two stages. The first stage involved researching relevant sources and rules concerning outburst hazard, and, subsequently, determining a number of parameters measured or observed in the mining industry that are potentially connected with the outburst phenomenon and can be useful when estimating outburst hazard. Then, the Author contacted selected experts who are actively involved in preventing outburst hazard, both in the industry and science field. The experts were anonymously surveyed, which made it possible to select the parameters which are the most essential in assessing outburst hazard. The second stage involved gaining knowledge from the experts by means of a questionnaire-interview. Subjective opinions on estimating outburst hazard on the basis of the parameters selected during the first stage were then systematized using the structures typical of the expert system based on fuzzy logic.

Keywords: coal and methane outburst, fuzzy logic, outburst hazard, experts' knowledge

Autor współpracował z polskimi ekspertami związanymi z badaniami i zwalczaniem zagrożenia wyrzutowego. W wyniku współpracy pozyskał ich wiedzę i doświadczenie, na bazie której stworzył system ekspercki, oparty na logice rozmytej. System umożliwia automatyczną ocenę zagrożenia wyrzutowego. Prace przebiegały w dwóch etapach. Pierwszy etap polegał na określeniu istotnych parametrów mierzonych, bądź obserwowanych w górnictwie, które mają silny związek ze stanem zagrożenia wyrzutowego. Następnie wybrana grupa ekspertów dokonała oceny stanu zagrożenia wyrzutowego, bazując na parametrach które w pierwszym etapie uznane zostały za najistotniejsze. Pozwoliło to zbudować system ekspercki na bazie logiki rozmytej, który określa stan zagrożenia wyrzutowego w zależności od bieżącej wartości analizowanych parametrów.

Słowa kluczowe: wyrzuty gazu i skał, logika rozmyta , zagrożenie wyrzutowe, wiedza ekspercka

* STRATA MECHANICS RESEARCH INSTITUTE OF THE POLISH ACADEMY OF SCIENCES, UL. REYMONTA 27, 30-059 KRAKOW, POLAND. E-mail: skoczyla@img-pan.krakow.pl

1. Introduction

More than 150 years passed since the first desrcibed outbursts, which took place in 1843 in France (Cao et al., 2001) and in England (Taylor, 1853). However, identifying these phenomena still requires numerous efforts, the aim of which is to ensure safety of the miners working underground. At present, it is impossible to precisely pinpoint the relevant parameters, nor the values of these parameters that would guarantee safe exploitation. Still, the research carried out over the years by teams of scientists (Litwiniszyn, 1987; Gil & Kwidziński, 1988; Tarnowski, 1995; Lama & Bodziony, 1996; Flores, 1998; Beamish & Crosdale, 1998; Topolnicki, 1999; Wierzbicki, 2003; Topolnicki et al., 2004, Xu et al., 2006; Kidybiński & Krause 2008, Wierzbicki & Dutka, 2010), as well as the experience gathered in mines (Jakubów et al., 2003; Tor et al., 2006), make it possible to identify the factors – and interrelations occurring among them – that are of extreme importance as far as the researched topic (i.e. estimating safety) is concerned.

The Author endeavored to consult some of the Polish experts who deal with assessing and preventing outburst hazards as to their knowledge and experience. On the basis of this knowledge, an expert system, based on fuzzy logic, was created. The system allows automatic assessment of outburst hazard. The work was completed in two stages. The first stage involved researching relevant sources and rules concerning outburst hazard, and, subsequently, determining a number of parameters measured or observed in the mining industry that are potentially connected with the outburst phenomenon and can be useful when estimating outburst hazard. Then, the Author contacted selected experts who are actively involved in preventing outburst hazard, both in the industry and science field. The experts were anonymously surveyed, which made it possible to select the parameters which are the most essential in assessing outburst hazard.

The second stage involved gaining knowledge from the experts by means of a questionnaire-interview. Subjective opinions on estimating outburst hazard on the basis of the parameters selected during the first stage were then systematized using the structures typical of the expert system based on fuzzy logic.

2. The first stage of gaining knowledge

A survey was administered to the group of selected experts actively involved in outburst prevention. The survey was constructed in such a way as to ensure compliance with sociological guidelines (Daniłowicz, 1992; Sztumski, 1995; Skawiński et al., 2000), and its form and content were settled as a result of consultation with sociologists specializing in this type of research. The basic assumption was the anonymity of responders. Due to that fact, one could expect answers based not on standing regulations, but on expertise and experience gained by the experts in the course of their professional career.

The way of selecting the research sample entailed choosing a group of people whose professional career – in industry as well as in science – involves identifying, assessing and preventing outburst hazard in Polish mines. The interviewed experts represented four institutions of higher education and research, and five industrial institutions.

The first column of the main chart of the survey contains a list of parameters observed and measured in the mining industry. The Authors are of the opinion that these parameters can be of significance when estimating outburst hazard. The parameters were chosen on the basis of the analysis of relevant sources (Wierzbicki, 2003). Also, the Author took into consideration his own subjective opinions formed during laboratory studies and empirical research in mines. Additionally, empty fields were left for the responders to provide the parameters that were not included in the chart. The list of the parameters originally included in the survey can be found in Table 1.

TABLE 1

List of parameters originally included in the survey

No.	Parameter measured, observed	No.	Parameter measured, observed
1	Firmness of coal	15	Changes in layer occurrence
2	Methane desorption intensity index	16	Changes in coal structure
3	Cutting yield from small-diameter exploration holes	17	Cracks within coal solid
4	Methane content	18	Spattering of coal from sidewalls
5	Distance from the area of geological distortions disrupting the continuity of the seam	19	Daily progress of the coal face
6	Distance from the area of geological distortions not disrupting the continuity of the seam	20	Results of geophysical measurements, in particular seismic and seismic-acoustic measurements
7	Increased amount of gas in the coal face after blasting works	21	Changes in the barometer pressure
8	Ash content	22	Seam thickness
9	Volatile elements content in coal (Vdaf)	23	Depth of coal occurrence
10	Humidity content in coal	24	Inclination of the excavation
11	Moist cuttings, changes in the seam humidity, the appearance of water in the hole	25	Carrying out mining activities in an unexplored area of the seam
12	Increased amount of yield in the coal face after blasting works	26	Changes in the temperature of coal solid
13	Gas exhaustion from the hole	27	Other suggestion
14	Cuttings exhaustion from the hole	28	Other suggestion

The second column of the survey contains fields in which the respondents determined – using the scale from 0 to 6 – to what extent, to the best of their knowledge and experience, a given parameter is related to the outburst phenomenon (i.e., how useful it is when assessing outburst hazard, "6" being the most useful).

The survey was sent to 32 respondents in total. The Author received 23 completed surveys (the indicator of survey response was 72 percent). Further statistical analysis, presented below, is based on these responses.

2.1. The statistical analysis of the obtained results

Using a scale from 0 to 6, the surveyed experts evaluated the significance that – in their opinion – each of the above parameters has when it comes to the risk of an outburst occurrence. The graph below (Fig. 1) presents the averaged set of answers. The parameters were assigned numbers accordingly to the Chart 1 contents.

Among the 26 parameters, there were five with the average result greater than 5.0. These were:
- firmness of coal (significance: 5.11),
- methane desorption intensity index (significance: 5.20),
- distance from the area of geological distortions disrupting the continuity of the seam (significance: 5.32),
- gas exhaustion from the hole (significance: 5.21),
- cuttings exhaustion from the hole (significance: 5.21).

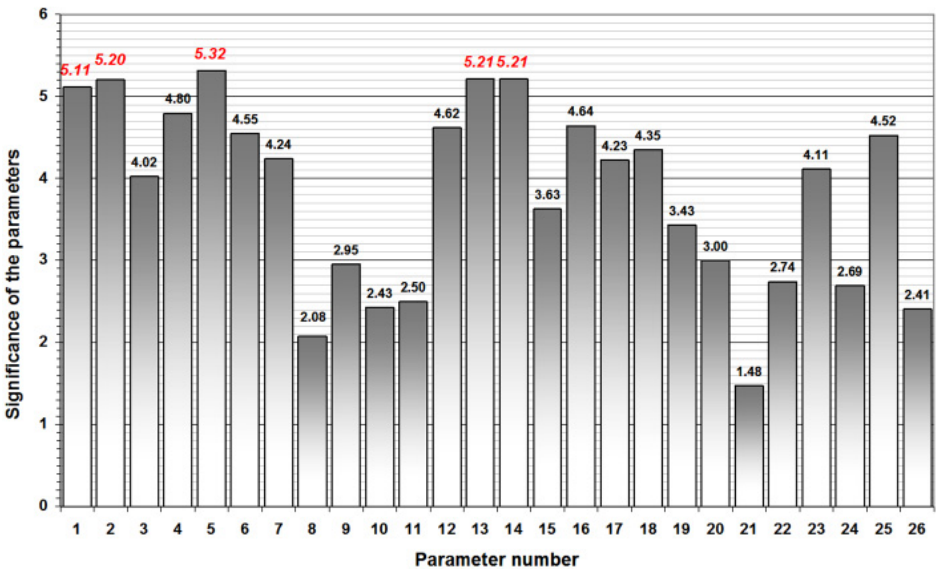


Fig. 1. The averaged set of answers given by the responders concerning the significance of selected parameters in evaluating outburst hazard

2.2. Description of parameters regarded by the experts as the most significant

The results of the survey in question carried out among the group of experts reveal five factors of particular relevance: the methane desorption intensity index, firmness of coal, the distance from the area of geological distortions disrupting the continuity of the seam, and the exhaustion of gas or/and cuttings from the hole.

2.2.1. Methane desorption intensity index

The methane desorption intensity index *dP* is a quantity that denotes the amount of methane released from a coal sample whose mass is ca. 3 g. The measurement is carried out by means of a manometric desorbometer after 120-240 seconds since the beginning of drilling the appropriate section of the exploration hole. Before they are placed in the receptacle of the desorbometer, the cuttings being released from the hole are sieved through so that the required grain fraction (0.5-1 mm) is separated. The measurement result is expressed in kPa.

The parameter in question belongs to a wide group of parameters describing the initial intensity of desorption. Its value depends mostly on the original pressure of gas and on the coefficient of gas diffusion in coal. In various countries, the parameter has many equivalents. In the Czech Republic (Rozhodnutí OBÚ v Ostravě č.j.3895/2002), it is the parameter V, which denotes the intensity of desorption from the sample of mass 10 g within a time period of 35 s. In Germany (Richtlinien… 1996), the parameter K_t was introduced. In Australia (Identify and Collate Leading Safety Technologies…), the parameter that is measured is the speed of the Hargraves emission (emission of gas from a coal sample of mass 4 g, grain fraction 0.125-0.5 mm, between the 2nd and the 6th minute). Finally, in China, the parameter ΔP is used – it denotes the initial speed of gas desorption from coal (Mining Safety Law, 1995r.).

2.2.2. Firmness of coal

The methodology of establishing the firmness index f is based on the assertion that the work needed to overcome the firmness of rock is proportional to a newly created surface and the volume of a crushed rock (Rittinger law (Brach 1962, 1963, 1968) and Kick-Kirpichev law (Sokołowski, 1990)). The guidelines and the early method of establishing firmness were proposed in 1951 by Protodiakonov.

In various countries, equivalents of the firmness index are employed by the mining industry, with the mechanical resistance of coal being determined indirectly by means of the work needed to crush it: the Czech Republic – the grindability index F_3; China, Russia – firmness in Protodiakonov's interpretation.

2.2.3. Exhaustion of gas and cuttings from the hole

The exhaustion of gas and cuttings from the hole is a phenomenon consisting in an intensive outflow of cuttings and gas taking place during drilling an exploration hole. The phenomenon occurs when the drill encounters an area of an increased content of free gas and a substantial permeability of rocks. A sudden transportation of cuttings occurs, propelled by the energy of the accumulated gas. The exhaustion of gas and cuttings is mentioned as a significant risk factor in Polish, Russian, Czech, German, and Chinese instructions.

2.2.4. Proximity of the area of geological distortions

In hard coal seams, there are areas that are particularly dangerous and particularly prone to occurrence of hazards connected with rock and gas outbursts. These areas reveal a different (i.e. less solid) structure of coal. Such forms can occur in the vicinity of geological distortions, resulting from strains in the strata. As a result of the effect of tectonic phenomena on a hard coal seam, cracks can appear in the latter. One can also observe pulverization or grinding of the rock material. In extreme cases, the original structure of the coal can be totally blurred (Fig. 2) (Cao et al., 2000; Shepherd et al., 1980; Młynarczuk & Wierzbicki, 2009). In the instructions concerning mining safety in most countries, one can find information on the significance of this parameter in evaluating outburst hazard.

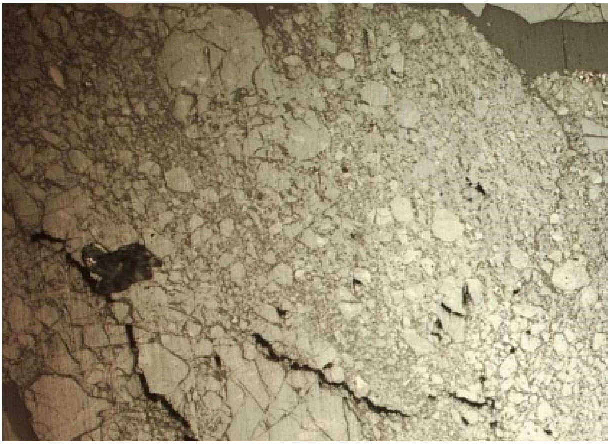


Fig. 2. A microscopic picture – optical enlargement 200X, reflected light – a piece of vitrinite coal – the original coal structure is totally blurred

2.2.5. Increased amount of yield after blasting works

The usefulness of this parameter in assessing outburst risk was evaluated by the experts as below 5.0. At the same time, unanimity among the experts as to the parameter's significance was the greatest. The parameter concerns observing the amount of yield in relation to the yield obtained in a standard manner, with the same technology of performing blasting works. This phenomenon might stem from both gas and geomechanic processes. It can attest to a large amount of gas that accumulated in the rock having performed extra work when overcoming the firmness of the solid materials, and to its further transportation. Geomechanic origins of the phenomenon are the evidence of a decreased firmness of rocks, or of the existence of a system of mechanical strains in the strata, conducive to pulverization of the rock material.

3. The second stage of gaining knowledge essential for determining the membership function and the set of rules for the expert system based on fuzzy logic

The presented system for forecasting outburst hazard, constructed on the basis of fuzzy logic, employs knowledge and experience of engineers and scholars. This knowledge needs to be coded as a set of rules and a membership function (Biacino & Gerla, 2002; Yager & Filev, 1994; Zadeh, 1965). Cause-effect relationships (the set of rules), complete with membership functions, represent the body of knowledge (subjective in the case of each expert) as to the evaluation of risk level quantitywise. Obtaining such knowledge is a task far more difficult than assessing the factors that are most essential for an occurrence of outburst hazard. The form of study applied in this case is closer to a questionnaire-interview (Lutyńska & Welland, 1983; Sztabiński, 1997).

The questionnaire-interview was carried out among a group of experts limited to twelve members only. The experts were chosen after a thorough analysis of the survey results, discussed in the previous chapter. The answers which were considered the most essential for evaluating outburst risk by the respondents in general were subjected to analysis. For all respondents, averages of significance attributed to these parameters were calculated. As a result, twelve experts who valued the most the five parameters considered by all the respondents as the most significant were chosen. These experts were subsequently involved in the second stage of gaining knowledge, as it seemed vital to guarantee the respondents an opportunity to discuss estimating outburst risk in terms of quantity, on the basis of the parameters that were regarded as the most significant ones by the experts at large.

On the basis of the previously mentioned survey carried out among the experts, a set of five parameters was selected. These were the parameters for which the obtained averages of significance attributed to them (in a scale from 1 to 6) exceeded 5. Gas exhaustion from the hole and cuttings exhaustion from the hole were considered as equally significant. Additionally, taking into consideration the physics of the phenomenon – where a sudden transportation of cuttings from the hole is caused by a dynamically released gas – these parameters will from now on be considered collectively, as cuttings and gas exhaustion from the hole. The conversations that the Author had with the experts resulted in selecting two additional parameters to be subjected to further analysis. These are increased amount of yield after blasting works and changes in coal structure.

Out of the six parameters being considered, two are quantitative in its nature: firmness of coal *f* and desorption intensity indicator *dP*. These will be treated as basic parameters, i.e. input variables for the expert system. The remaining input parameters, treated as additional indicators, are symptomatic. They inform us whether a given phenomenon has been observed or not, and it is difficult to analyse them quantitywise. Thus, the constructed expert system is going to be based mainly on the analysis of the gas-geomechanic situation represented by the desorption intensity index and the firmness of coal. On the basis of these parameters, current levels of outburst risk are going to be determined. Additional parameters are of substantial significance when it comes to informing about an increase in the risk level. It was assumed that when one, two, or more additional parameters are reported, an adequate number of percentage points will be added to the level of outburst risk calculated on the basis of *f* and *dP* and expressed as a percentage.

An obvious output variable is a parameter known as outburst hazard. The number of linguistic variables describing the input parameters, as well as the output parameter, was determined as 5. The shape and the form of the membership function describing the linguistic notion of the output variable (outburst risk) was determined beforehand. Describing outburst hazard by means of membership functions entailed application of triangular membership functions, evenly distributed in the considered domain (see Fig. 3).

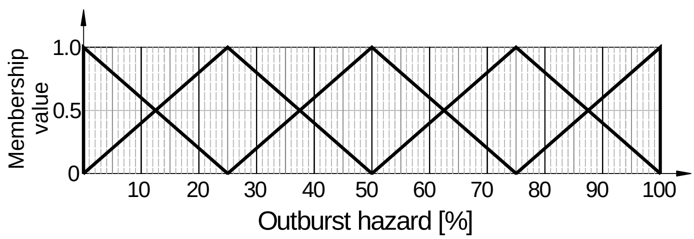


Fig. 3. Membership functions of the output variable – outburst hazard

Completing the questionnaire-interview with an expert made it possible to:
- plot the shapes of membership functions describing the linguistic notions of the input variables,
- establishing a full set of rules (25 rules),
- calculating a percentage-point increase of the estimated outburst hazard – determined on the basis of the firmness index and the desorption intensity index – in a situation when the following phenomena are observed:
  - gas and cuttings exhaustion from the hole,
  - close proximity of an area of geological distortions (less than 6 m),
  - an increased amount of yield after blasting works,
  - changes in the coal structure.

The most difficult task in the discussed stage of gaining expert knowledge was determining the membership function for the input variables. In practice, this consisted in asking the experts a series of supplementary questions. It was determined which physical values correspond "most closely" to particular linguistic notions – these were the peaks of the membership functions. Subsequently, the values of parameters for which the discussed linguistic notions were no longer "valid" were determined – in this way, the domain of fuzzy subsets was established. Out of the proposed shapes of the membership functions, the experts would choose triangular or trapeze-shaped functions. The trapeze-shaped functions were chosen mostly for describing extreme linguistic notions (very low – very high); for other linguistic variables, the experts would choose triangular functions. In most cases, once provided with explanations necessary for plotting first membership functions, the experts would plot the remaining ones themselves.

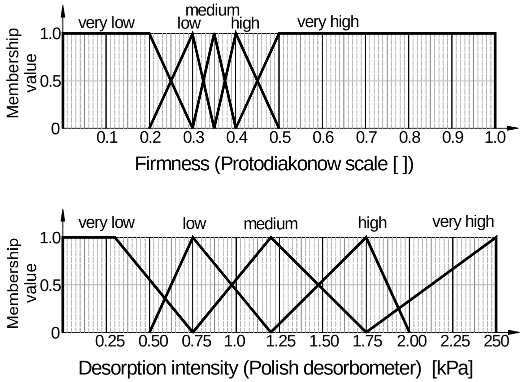
Due to a relatively small number of rules, drawing up a set of rules consisted in answering 25 questions – what, in the expert's opinion, is the level of outburst hazard, if the desorption intensity index is [a linguistic notion], and the firmness of coal is [a linguistic notion]. While compiling the set of rules, experts could access the previously plotted membership functions, so that the applied linguistic notions corresponded to their placing on the physical domain of a given parameter.

An example of a shape of a membership function, together with a set of rules obtained from one of the experts, was presented in Figure 4.

3.1. Implementation of the expert system

The obtained expert knowledge was implemented in an original computer software, complete with all the modules necessary for performing the process of fuzzy inference (by means of Mamdani's method) and generating the result. Calculating the value of outburst hazard on the basis of the expert system for pairs of points *dp*, *f*, from ranges $f \in (0–1)$ [ ], $dP \in (0–2,4)$ [kPa], with the step being 0.1, makes it possible to determine "an area of risk". It is a contour graph, on which the levels of outburst hazard are represented by colours ranging from green (minimal hazard) through yellow (moderate hazard), to red (the highest level of hazard). An "area of risk" determined on the basis of membership functions and the set of rules from the discussed exapmple was depicted in Figure 5.

The Author suggests that the averaged "area of risk" should be regarded as the end result, presenting the results generated by the expert system of assessing outburst hazard. The averaged value of hazard for every pair *f*, *dP* within the area of risk is calculated as the arithmetic mean



		Firmness				
		very low	low	medium	high	very high
Desorption intensity	very low	low	very low	very low	very low	very low
	low	medium	medium	low	very low	very low
	medium	high	medium	medium	low	low
	high	very high	high	high	high	high
	very high	very high	very high	very high	high	high

Fig. 4. An example of a shape of a membership function, together with a set of rules

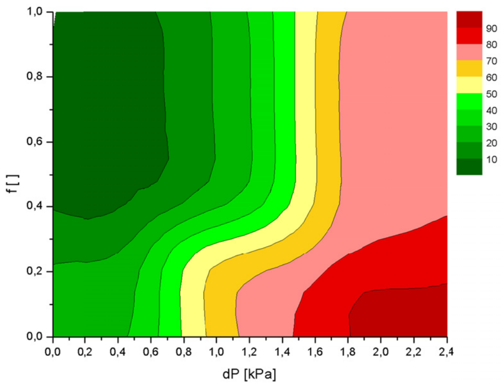


Fig. 5. An "area of risk" determined on the basis of membership functions and the set of rules from the discussed exapmple

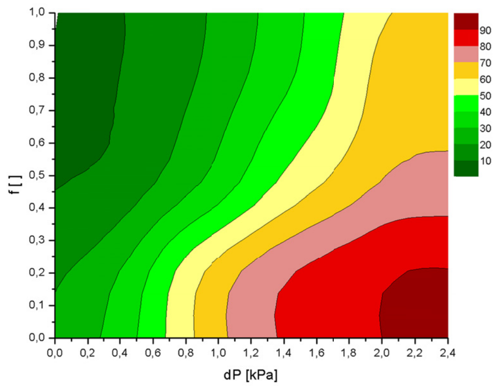


Fig. 6. Averaged "area of risk"

of the values of hazard determined by expert systems constructed on the basis of twelve experts' knowledge and experience (Fig. 6).

The graph is intuitive. An increase in desorption intensity dP, with the constant value of firmness f, is accompanied by an increase in the level of outburst hazard. An analogical situation occurs when *dP* is constant, and the value of *f* decreases. Polish regulations concerning hard coal mining industry assume that the liminal values of *dP* and *f* are, respectively, 1.2 kPa and 0.3 (in Protodiakonov's scale). The outburst hazard for these values, calculated on the basis of the constructed expert system, is 50 percent.

3.2. Additional hazard symptoms

During the questionnaire-interview, apart from providing knowledge indispensable for the process of determining the membership functions and the set of rules, the experts answered the following question: by how many percentage points, to their best knowledge and experience, will the outburst hazard calculated on the basis of *dP* and *f* increase, if, as an additional factor, one of the four proposed hazard symptoms is observed? The obtained averaged results were presented in Table 2, and a sample illustration depicting the changes in the "area of risk" (with the hazard symptom "geological distortion in close proximity" taken into account) is provided by Figure 7.

TABLE 2

Additional hazard symptoms

Hazard symptom	Average value [pp]
Gas and cuttings exhaustion from the hole	65
Geological distortion in close proximity	55
Increased yield	56
Change in coal structure	52

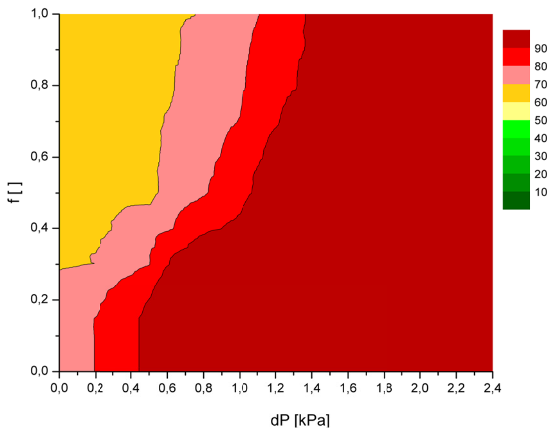


Fig. 7. The averaged expert area of risk in the function of *dP*, *f*, taking into account additional information about geological distortion in close proximity

The analysis of the area of risk in the function of *f*, *dP*, taking into account information about additional outburst symptoms, shows that, in experts' opinion, the level of risk exceeds 50 percent in each case, even for the values of *dP* approximating 0, and for the values of *f* approximating 1. It is an explicit confirmation of significance that the experts ascribe to the presented symptoms of outburst hazard.

4. Summary

In numerous cases, expert knowledge and experience constitute a valuable addition to mathematical models and inference based on analysing the physical aspects of a given phenomenon. This expertise can prove particularly valuable when a phenomenon being examined is a complicated one, such as the outburst of gas and rocks. The paper presents the full cycle of constructing an expert system based on fuzzy logic, where experts participated in every single stage of the project. In the first stage, by means of an anonymous survey, the group of experts pointed to parameters of the highest significance in the process of evaluating the level of outburst hazard. In the second stage, during a questionnaire-interview, the experts shared their knowledge and experience in a manner typical for fuzzy logic. This knowledge was subsequently implemented in an original software applying fuzzy inference and generating its results. The results were presented as an "area of risk".

The line of reasoning presented in this paper concerns the Upper Silesia Coal Basin and constitutes a form of a feasibility study. To adapt the expert system for the needs of a particular coal basin, a similar analysis has to be carried out. This would entail establishing which parameters are routinely determined in a given area, and subsequently choosing the most significant ones, and describing the hazard in a quantitative manner, by means of structures typical of fuzzy logic.

References

Beamish B., Crosdale P.J., 1998. *Instantaneous outbursts in underground coal mines: An overview and association with coal type*. International Journal of Coal Geology, 35, 27-55.

Brach I., 1962. *O teoriach rozdrabniania minerałów*. Przegląd Mechaniczny, nr 14, 421-426.

Brach I., 1963. *Podstawowe problemy w procesach rozdrabniania minerałów*. Ośrodek Wydawniczy Warszawa, IOMB.

Brach I., 1968. *Praca rozdrabniania ciał kruchych*. Przegląd Mechaniczny, nr 15, 429-434.

Cao Y., He D., Glick C.D., 2001. *Coal and gas outbursts in footwalls of reverse faults*. International Journal of Coal Geology, 48, 47-63.

Cao Y., Mitchell G.D., Davis A., Wang D., 2000. *Deformation metamorphism of bituminous and anthracite coals from China*. International Journal of Coal Geology, 43_2000.227-242.

Daniłowicz P., 1992. *Podręcznik Socjologicznych Badań Ankietowych*. Warszawa, IFiS PAN.

Flores M. Romeo, 1998. *Coalbed methane: From hazard to resource*. International Journal of Coal Geology, 35, 3-26.

Gil H., Swidziński A., 1998. *Wyrzuty gazów i skał*. Politechnika Śląska, Skrypty Uczelniane, Nr 1366, Wyd. II, Gliwice.

Hua G., Sheng X., David R., Srinivasa Y., Identify and Collate Leading Safety Technologies – "Coal Mine Health & Safety Strategy (CMHS)", Asia-Pacific Partnership (APP) partners: Australia, Canada, China, India, Japan, Republic of Korea and the United States of America (USA).

Jakubów A., Tor A., Tobiczyk S., 2003. *Wyrzut metanu i skał w drążonej lunecie rurowej II na poziomie 1000 m w KWK Pniówek okoliczności, przyczyny i skutki*. Szkoła Eksploatacji Podziemnej, Szczyrk.

Kidybiński A., Krause E., 2008. *Current Developments in Coal and Gas Outbursts Research Aimed at Assessment and Limitation of the Hazard in Mines*. 21st WMC & Expo, 207-220.

Lama, R.D., Bodziony J., 1996. *Outbursts of Gas, Coal and Rock in Underground Coal Mines*. R.D. Lama & Associates, Wollongong, NSW, Australia.

Litwiniszyn J., 1987. *Gas emission from a crushed rock medium during its sudden outbursts*. Arch. Min. Sci., Vol. 32, p. 155-168.

Loredana B., Giangiacomo G., 2002. *Fuzzy logic, continuity and effectiveness*. Archive for Mathematical Logic, Vol. 41, Nu. 7.

Lutyńskia K., Wejlanda A., P., 1983. Wywiad kwestionariuszowy - analizy teoretyczne i badania empiryczne: wybór tekstów pod redakcją Krystyny Lutyńskiej i Andrzeja Pawła Wejlanda. Published 1983 by Zakład Narodowy im. Ossolińskich in Wrocław.

Młynarczuk M., Wierzbicki M., 2009. *Stereological and profilometry methods in detection of structural deformations in coal samples collected from the rock and outburst zone in the "Zofiówka" Colliery*. Arch. Min. Sci., Vol. 54, No. 2, p. 189- 201.

Richtlinien des Landesoberbergamtes Nordrhein-Westfalen über die Abwehr von Gefahren des plötzlichen Freiwerdens großer Grubengasmengen mit oder ohne Auswurf von Kohle oder Gestein (Gasausbruchs-Richtlinien) vom 29.05.1996.

Rozhodnutí OBÚ v Ostravě č.j.3895/2002 a v Instrukci pro doly s nebezpečím průtrží hornin a plynů.

Shepherd J., Rixon L.K., Creasey J.W., 1980. *Analysis and prediction of geological structures associated with outbursts at Collinsville, Queensland*. The Occurrence, Prediction and Control of Outbursts in Coal Mines Symposium, Australian Institute of Mining and Metallurgy, Parkville, Victoria, Australia, 159-171.

Skawiński Z., Sztabiński P., Sztabiński F., 2000. *Podręcznik ankietera*, Warszawa, IFiS PAN.

Sokołowski M., 1990. *Energetyczny opis rozdrabniania*. Instytut Mechanizacji Budownictwa i Górnictwa Skalnego, Warszawa.

Sztabiński F., 1997. *Ankieta pocztowa i wywiad kwestionariuszowy*. Warszawa, IFiS PAN.

Sztumski J., 1995. *Wstęp do metod i badań społecznych*. Katowice, Śląsk.

Tarnowski J., 1995. *Obliczanie wyrzutów węgla i gazu*. Przegląd Górniczy.

Taylor T.J., 1852-53. *Proofs of subsistence of the firedamp at coal mines in a state of high tension in situ*. Trans. N. England Inst. Min. Engrs., Vol. 1, 275-299.

The Law of the People's, Republic of China on Safety in Mines (Mining Safety Law), 1995.

Topolnicki J., Wierzbicki M., Skoczylas N., 2004. *Rock and gas outbursts - laboratory tests and in-shaft measurements*. Arch. Min. Sci., Vol. 49, No. 1, p. 99-116.

Topolnicki J., 1999. *Wyrzuty skalno-gazowe w świetle badań laboratoryjnych i modelowych*. Studia Rozprawy i Monografie, nr 67, IGSMiE, Kraków.

Tor A., Jakubów A., 2006. *Wyrzuty metanu i skał w kopalniach Jastrzębskiej Spółki Węglowej S.A.* Materiały 4 Szkoły Aerologii Górniczej, Kraków, 159-176.

Wierzbicki M., Dutka B., 2010. *The influence of temperature changes of the structurally deformed coal-methane system on the total methane content*. Arch. Min. Sci., Vol. 55, No. 3, p. 547-560.

Xu T., Tang C.A., Yang T.H., Zhu W.C., Liu J., 2006. *Numerical investigation of coal and gas outbursts in underground collieries*. International Journal of Rock Mechanics & Mining Sciences, 43 905-919.

Yager, R.R., Filev, D.P., 1994. *Essentials of Fuzzy Modeling and Control*. John Wiley & Sons, New York.

Zadeh L.A., 1965. *Fuzzy Sets*. Information and control, 8, 338-353.

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