ISSN 1848-0071
UDC 620.262+662.33=111
Recieved: 2012-12-01
Accepted: 2013-01-14
Original scientific paper

APPRAISAL OF THE POPULATION THREAT RISK BY CARBON LEAKAGE PRODUCED BY UNDERGROUND COAL GASIFICATION

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The UCG /underground coal gasification/ technology could increase energy production resulting in improving the economic situation. Even if the risk of accidents may occur in the both coal gasification and underground mining, the other parameters suggest that the coal gasification method is much safer that the underground mining.
Key words: underground coal gasification technology (UCG), environmental impact, carbon leakage.

Procjena opasnosti za stanovništvo pri gubljenju ugljika u procesu plinificiranja ugljena. Tehnologija UCG / podzemno plinificiranje ugljena/ mogla bi povećati proizvodnju energije što rezultira poboljšanjem ekonomske situacije. Čak iako se nezgode mogu pojaviti tijekom plinificiranja i kopanja ugljena, ostali parametri ukazuju na to da je metoda plinificiranja mnogo sigurnija od kopanja.
Ključne riječi: tehnologija podzemnog plinificiranja ugljena (UCG), utjecaj na okoliš, ugljik.

INTRODUCTION

The exploitation of the coal is usually performed by underground and open pit mining. However, a large volume of the deposits is left after the mining due to unsuitable mining conditions (geological structure, hydrogeological conditions etc.). Generally, it is possible to exploit little bit more than 60% of the reserves in the Slovakian coal mines.

Recently, a new technology appeared for utilization of coal left after the mining process. This is so called coal gasification technology (UCG). Underground gasification is conversion of solid or liquid fuel to gaseous fuel, which takes place in coal seams. The gasification media exposure leads to decomposition of organic matter which form tars, gaseous products and solid residue slag and ash due to high temperatures.

The underground coal gasification means a controlled burning of coal in underground coal deposit. The principle is based on the existence of at least two wells (often a series of wells), namely the injection and production well drilled into the coal seam and a system for cleaning and storage of the produced gas. Through the injection borehole oxygen is pumped into the coal seam resulting in coal ignition , and production of coal gas, which is taken to the surface by exploitation well.

ENVIRONMENTAL IMPACTS OF UCG OF THE POPULATION

UCG technology belongs to the so-called "clean coal technologies". The environmental dangerous impacts may occur during this process as well as by other manufacturing and production processes.

When choosing the operation it is necessary to take into account the possible contamination of environmental components (water, soil, air) and also the depth of coal seams. The character of cavity fills is also considered as the UCG process may result in the subsidence in the areas with high cavity occurrences. To minimize adverse impacts on the environment it is necessary to ensure control of groundwater survey and performance of preliminary risks analysis.

Preliminary risks analysis according their impacts may be done in following fields:

- drilling activities: noise, a subsidence of well areas, increased transport of heavier transport vehicles,
- according to methods of the UCG technology:
  - danger of uncontrolled underground coal gasification,
  - carcinogenic waste (coal tar), which could contaminate undergroundwater
  - danger of underground explosions,
  - emission of gases, which can reach the surface,
  - subsidence, which may occur even after several years,
- general effects:
  dust and air pollution at the time of production,
  - residential areas are not suitable for research.

The most important economic territory of the Slovak brown coal deposits are currently Nováky, Handlová and Cigeľ areas located in the Upper Nitra Depression in the Late Badenian strata. They are developed in an area of about 70 km^2 [2].

The next part of this paper is devoted to the risk analyses concerning a leakage of emissions to the surface (e.g. fault of pipelines) and risk related to the health of population due to leakage while using underground coal gasification technology.

DETERMINATION OF THE CHEMICAL EXPOSURE INDEX (CEI)

Chemical Exposure Index (CEI) has developed and introduced in 1986 by chemical company DOW. CEI together with index for fire and explosion hazard (FEI) are tools for estimation of potential risks.

The CEI method is based on an index, which is independent on frequency of events and is given universally. This index provides a simple method for determining the risk of toxicity, human health hazards in the vicinity of chemical plants due to possible chemical accidents. CEI provides a relative indication and it is used for initial analysis of risk processes (PHA), to calculate the dose distribution index (DRI) in planning of security measures.

THE CALCULATION PROCEDURE OF CEI

Based on required information the coefficient CEI and dangerous distance may be calculated.

Procedure for determining the index of CEI:

1. Determination of potential effects of chemical accidents.
2. Establishing of ERPG-2EEPG-2.
3. Designation of released quantity (AQ) in the scenario.
4. Selection of scenario with the largest selection of loose quantity (AQ).
5. Calculation CEI.
6. Calculation of hazardous distances (HD).
7. The complete summary list of CEI.

A fundamental step is to identify the source of the threat of potential threats and determining the types of toxic substances that may escape in an accident and therefore will be considered in determining the CEI and dangerous distances.

For the types of chemicals it is necessarily to determine the value of the ERPG. Attributes were published by ERPG American Society for Industrial Hygiene (AIHA). These values serve as an estimate of the concentration and effects. ERPG (a guide for planning security operations) is equivalent to EEPG (instructions for hazardous exposure) according to the DOW.

LEVELS OF CATEGORIZATION ACCORDING TO THE ERPG / EEPG

ERPG-1/EEPG-1: maximum concentration, which can tolerate a person during one hour without significant health changes. ERPG-2/EEPG-2: maximum concentration, which can tolerate a person during one hour not resulting into irreversible health changes. ERPG-3/EEPG-3: maximum concentration, which can tolerate a person for one hour without being fatally endangered. In the absence of values ERPG / EEPG it is recommended to determine:

ERPG - 2

1. Use guide for the workplace and the type of exposure:

- TLV-STEL: Threshold limit value - Short-term exposure limit or use another threshold quantity,
- Use triple the value of TLV-TWA: Threshold limit value - Time weighted average.

2. If there is no guide to the workplace, to request the assistance of the industrial hygienist ERPG – 3

1. LC50 divide by 30.
2. Apply fivefoldvalue of the ERPG-2.

or

1. Use threshold.
2. Use ERPG-2 value divided by 10.

The next step is to determine the quantities of toxic substances released into the atmosphere (AQ), taking into account all possible operating scenarios of accidents (for each accident is considered that lasts at least 5 minutes). In determining the most probable events we start from past experience from chemical plants.

In determining the value of AQ we can come out from the known volume flow or is it possible to establish the following relationship:

$$AQ = 4.751x10^{-6} xD^2 xP_a x\sqrt{\frac{M_k}{T+273}}$$

[kg.s^{-1}]

where:
P_a - absolute pressure (P_g + 101.35) [kPa]
P_g - operating pressure [kPa]
M_h- molecular material weight
T – temperature [kPa]
D - diameter of hole [mm].
Basic conditions for the assessment are therefore temperature, pressure and pipe size.

After the assessment a value of maximum leakage is given in order to calculate the CEI.

The next step is to calculate the actual CEI and dangerous distances for each ERPG values, the base value is considered to ERPG-2. For calculation of the CEI index wind speed 5 m. s^{-1} and a mild weather is considered.

Determined values are based on the following links:

Chemical Exposure Index (CEI)

$$CEI = 655{,}1x\sqrt{\frac{AQ}{ERPG}}$$

where:
AQ - amount of released substance [kg.s^{-1}]
ERPG-2 - the value of ERPG-2 [mg.m^{-3}]
If CEI is greater than 1000 then CEI = 1000

Dangerous distance

Dangerous distance is expressed for the concentrations ERPG-1, ERPG-2 and ERPG-3.

$$HD = 6551\,x\sqrt{\frac{AQ}{ERPG}} \text{ [m]}$$

where:
AQ - released quantity [kg.s^{-1}]
ERPG - ERPG-1, ERPG-2 and ERPG-3 [mg.m^{-3}]
If a dangerous distance is greater than 10 000 m, then HD = 10 000 m .

ASSESSMENT OF GAS LEAKAGE RISK BY USING UCG

The coal gasification process evaluation is based on the analysis of single components “syngas” in trials performed in solving “APVT project” at the BERG Faculty, Technical University of Kosice (Table 1 and 2). The carbon monoxide (CO) can be regarded as the most dangerous component considering its toxicity and high proportions of the mixtures studied. For this reason, the risk of exposure to the surrounding population will be assessed in case of gas leakage produced in the operational accident.

In the tables 1 and 2 there are the statistical characteristics of individual components “syngas” for all experiments conducted between 2009 and 2010. They include:

- mean;
- standard deviation;
- maximum value,
- minimum value.

These characteristics were calculated for two criterias. In the first criterion the “syngas” heat value was greater than 3 MJ.m $^{-3}$ (the effective time of gasification) and in the second one it is higher than 0, which corresponds with values of the all experiment.

Table 1. Statistical characteristics of the components "syngas" in trials performed in 2009 [6-8-9]
Tablica 1. Statističke karakteristike komponenti "sintetskog plina" u pokusima provedenim u 2009 [6-8-9]

exper.	SYNGAS components	H > 3 MJ/m^3				H > 0 MJ/m^3			
		mean	**standard deviation**	**max.**	**min.**	**mean**	**standard deviation**	**max.**	**min.**
I.09	H_2	16,59	8,28	35,57	0	14,40	9,11	35,57	0
	CO	10,40	6,64	31,69	0	9,09	6,79	31,69	0
	CH_4	16,90	5,12	20,67	0	14,74	6,82	20,67	0
	CO_2	19,77	4,24	31,39	0	18,37	5,34	31,39	0
	O_2	2,24	3,78	21	0	3,34	5,08	21	0
II.09	H_2	10,04	7,48	29,97	0	1,19	2,94	29,97	0
	CO	10,81	9,29	30,54	0,8	1,46	3,19	30,54	0,01
	CH_4	7,78	8,10	46,37	1,58	2,70	2,47	46,37	0
	CO_2	30,44	14,09	49,96	8,72	16,65	12,91	49,99	0,05
	O_2	1,93	3,02	13,36	0,04	11,99	8,41	21	0,03
III.09	H_2	9,14	2,58	15,21	1,38	0,95	2,15	15,21	0
	CO	9,16	4,36	19,52	2,34	1,11	2,13	19,52	0
	CH_4	4,31	2,11	14,79	1,93	0,53	0,95	14,79	0
	CO_2	28,84	13,37	49,71	6,82	15,68	10,31	49,81	0
	O_2	1,79	3,59	12,2	0	12,67	8,01	20,92	0
IV.09	H_2	13,34	7,17	40	0	10,12	7,62	40	0
	CO	15,23	8,71	49,73	0	11,12	9,26	49,73	0
	CH_4	7,66	5,72	59,75	0,96	5,93	5,34	59,75	0
	CO_2	24,20	8,68	49,89	0,71	22,07	9,54	49,89	0
	O_2	0,62	2,17	17,43	0	1,51	4,20	20,96	0

Table 2. Statistical characteristics of “ syngas” components in trials performed in 2010 [6-8-9]
Tablica 2. Statističke karakteristike komponenti "sintetskog plina" u pokusima provedenim u 2010 [6-8-9]

exper.	SYNGAS components	H > 3 MJ/m^3				H > 0 MJ/m^3			
		average	standard deviation	max.	min.	average	standard deviation	max.	min.
I.10	H_2	8,23	3,76	19,26	0,26	1,75	2,52	19,26	0
	CO	4,65	1,72	11,33	1,03	1,35	1,43	11,33	0
	CH_4	7,28	3,25	21,45	3,60	1,80	2,08	21,45	0
	CO_2	15,21	3,64	27,81	3,43	9,92	4,97	27,81	0
	O_2	1,58	2,36	14,31	0	7,76	6,56	20,96	0
II.10	H_2	5,14	5,64	32,23	0	2,84	4,24	32,23	0
	CO	7,62	4,79	39,50	0	5,30	4,42	39,50	0
	CH_4	12,04	6,67	52,10	0	6,55	6,60	52,10	0
	CO_2	19,55	9,42	49,85	0	15,01	9,07	49,85	0
	O_2	1,25	2,17	13,01	0	4,59	6,24	20,94	0

The maximum value of the CO share in the compound at the required heat value greater than 3 MJ.m^{-3} reached value 49.73 % as is shown in Tables 1 and 2. The average value obtained from all experiments was 9.65 %. In the case that the heat value was not given, the maximum ratio of the CO syngase was 49.73 % and the mean obtained value of all experiments was 4.9 %. The value of the risk of possible leakage should be calculated for the maximum risk and thus for the maximum value of the CO share of “syngas”. The average density of the conducted output syngas was 0.96 kg m^{-3}.

Estimated power of the generator was designed 6000 Nm^3.hod $^{-1}$. The values of ERPG of carbon monoxide by AIHA are follows: ERPG-1 = 230 mg.m^{-3}, ERPG-2 = 403 mg.m^{-3}, ERPG-2 = 575 mg.m^{-3}. Based on the above parameters and experimental result the values of the index chemical exposure as well as the values of hazardous distances depending on the category ERPG were estimated for coal gasification. The results of these calculations are summarized in Table 3, where the values of the maximum (49.73 %) and average (9.65 %) ratio of CO are mentioned in the composition of the experimental results. Guiding values are the values determined by the maximum of CO. These values will serve as an outcome for a definition of endangered groups depending on the analyzed health risk given by the description of individual categories of ERPG.

Values for the average ratio of CO are shown only for comparison.

Table 3. Calculated values of the index chemical exposure and hazardous distances
Tablica 3. Izračunate vrijednosti indeksa kemijske izloženosti i udaljenosti opasnosti

Fixed parameter	Values for max. ratio of CO in „syngas“ (49,73 %)	Values for average ratio of CO in „syngas“ (9,65 %)
CEI	29,1	12,9
HD (ERPG-1) [m]	385	170
HD (ERPG-2) [m]	291	129
HD (ERPG-3) [m]	243	108

EVALUATION

The calculations of the carbon leakage risk shows following unsafe distances (Table 4). An excess of these distances can cause the health threats of persons. These values are related to the exposure time - 1 hour.

Table 4. The data concern of the period of exposure - 1 hour
Tablica 4. Podaci koji se odnose na period izloženosti- 1 sat

Distance [m]	Effect of CO on the population
> 385	without significant health changes
384- 291	no irreversible health changes
290- 243	non-fatal threat
< 242	threat of death

Increasing of the released amount of CO will shorten the distance of range of its reach. The shortening the distance from the source of CO (location of the leak) reduces the time interval during which it may come to death of vulnerable persons.

CONCLUSION

CEI has been used for determination of the chemical hazard index for storage and transport of carbon dioxide for UCG. The above calculation shows that the surrounding villages of Baňa Cígeľ should not be directly threatened by CO in the case of gas leakage from this generator /possible evacuation of people by 1 hour/. However, it may come to the endangering of persons who enter in the given time the defined distances given in Tab. 4. Also legislative coming from the act of National Council of Slovak Republic no. 261/2002 of the prevention of industrial accidents must be kept. These act sets the conditions in enterprises which use of hazardous substances e.

For the implementation of the Act were adopted two implementing regulations - Regulation of Ministry of environment Slovak Republic no. 489/2002, which implements certain provisions of the prevention of major industrial accidents and the amendment of certain act and regulations Ministry of the Environment. 490/2002 Z. z. the safety report and the emergency plan [11].

Acknowledgement

Research presented in this paper was supported by the Scientific Grant Agency (VEGA) of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences, Grant No. 1/0370/10 No., Grant No. 1/11/1206/12. and Project No. APVV-0582-06.

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