Application of High Density Emulsion Explosives in VCR Mining Method

by Wang Xuguang

Application of the theory of blasting crater by L. C. Lang of Canada Industry Ltd. to mining practice brought into being the so-called Vertical Crater Retreat method of VCR for abbreviation (1, 2). Based on such theory and with large diameter longhole blasting technique as premiss, this new underground mining method can make full use of the blasting advantages of spherical charge and has such advantages as higher efficiency, less mining preparation work, lower cost, safer working condition etc.

Mining practice shows that slice blasting with spherical charge of high density, high detonating velocity and high strength explosives is a key technique to realize VCR method in practice.

To promote the realization of VCR method BGRIMM successfully developed CLH series emulsion explosives. Having high density (1.35-1.55g/cm^3), high detonating velocity (4,500-5,500 m/sec) and high strength (the volume strength of CLH is 150-220 suppose that of rock explosive No.2 as 100), these explosive products satisfactorily meet the requirements set by this mining method. A lot of experimental crater blasting work was done in the representative rocks at Fankou Lead and Zinc Mine, followed by VCR blasting operations completed in two experimental stopes and one production stope. All together 16 rounds of spherical charge slice blast and 2 rounds of column charge in combination with partially spherical charge blast were shot, consuming 25.5 tons of CLH-2 explosive with 95,000 tons of ore broken down.

Practice in Fankou Mine shows that CLH series emulsion explosives are very effective and suitable for VCR mining method and the technico-economical results achieved are satisfactory.

In this paper particular emphasis is placed on the types and characteristics of CLH emulsion explosives, cratering tests as well as their application in VCR mining and the results obtained.

1. Types, Characteristics and Package Specifications of CLH Explosive

1.1 Types of product

Experience shows that the density and explosiveness of final products should be given primary consideration when designing different types of CLH series emulsion explosives, i.e., such different types should have different density, detonation velocity and strength so as to match with rocks which have various characteristics. Now, there are four types of CLH series i.e., CLH-1, CLH-2, CLH-3 and CLH-4 with both increasing density and strength to fullfill the requirements of VCR mining in various geological conditions with different rock/ore types. Generally, CLH-1 and CLH-2 are used for VCR mining in medium-hard rocks whereas CLH-3 CLH-4 suitable for hard rocks with poor blastability.

1.2 Main Features

1.2.1 Physical appearance

It is known that the appearance of emulsion explosives changes as the external phase viscosity varies. The product itself can be flowable soft paste of nonadhesive elastico-plastic substance. Acording to the practical requirement of blasting operation, finished products of CLH have an appearance of soft,

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Table 1 Performance of CLH products

Item \ Product	CLH-1	CLH-2	CLH-3	CLH-4
Density (g/cm³)	1.35-1.40	1.40-1.45	1.45-1.50	1.48-1.55
Detonation velocity (m/sec)	4500-5500	4500-5500	4500-5500	4500-5500
Critical diametre (mm)	60	60	60	60
Crater volume (m³)	2.48	4.29	3.67	--
Water resistance	Excellent	Excellent	Excellent	Excellent
Storage period (month)	≥6	≥6	≥6	≥6

plastic paste with the colour varying from silver gray to light brown, while the density ranges from 1.35-1.55g/cm³.

1.2.2 Performance

Data concerning the performance of CLH products are given below in Table 1, including explosiveness, water resistance and storage stability.

1.2.3 Safety features

To ensure safe deep-hole blasting, it is of vital importance to test safety features of CLH series emulsion explosives in all respects, including impact, friction, flame and shooting sensitivities, thermodecomposition and poisonous gas release. All these were measured and the results are shown in Tale 2.

1.3. Package Specification

1.3.1 Package of explosives

CLH series explosives are packaged in plastic bags of 150 mm in diameter. To meet requirements of different experimental stopes, the explosive bags have weight of 5 kg, 10 kg and 12.5 kg respectively.

1.3.2 Primer charge

Primer charge is casted with RDX and TNT (RDX : TNT =1 : 1), each primer weighs 200 grams.

2. Cratering Test (3)

2.1. Principles

Crater blasting is a blasting operation with spherical charge confined at a certain depth; when the charge is detonated fractures will spread radially all over the surrounding rock medium within the blast effecting zone.

Figure 1 and 2 illustrate the occurring and developing of the crater as well as the distribution of fractured zone around the crater.

Summing up the results of his long-term ressearch work, C.W. Livingston pointed out when the amount of energy consumed in rock-breaking gets to its maximum i.e. the volume of the blast crater gets to its

Table 2 Safty features of CLH series emulsion explosives

Item \ Type	CLH-1	CLH-2	CLH-3	CLH-4	Notes
Impact sensitivity (%)	0.0	0.4	0.0	16.16	48±2 for tetryl
Friction sensitivity (%)	0.0	4.4	0.0	0.0	12-14 for tetryl
Flame sensitivity	no	no	no	no	
Shooting sensitivity	no	no	no	no	
Thermodecomposition point (℃)	220-392	230-380	232-378	222-305	
Poisonous gas yield (l/kg)	16-22	16-22	16-22	16-22	

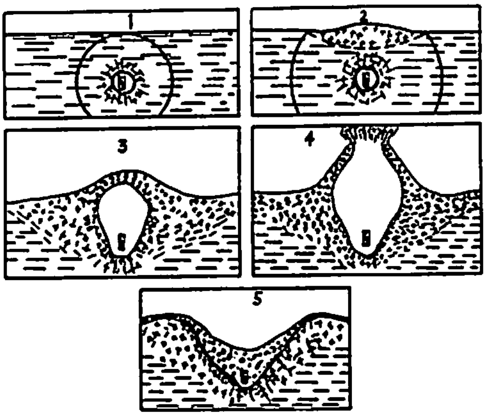

Fig. 1 Key events in crater formation.
1. Stress wave reaches surface
2. Surface spails
3. Gas acceleration
4. Venting
5. Crater formation complete

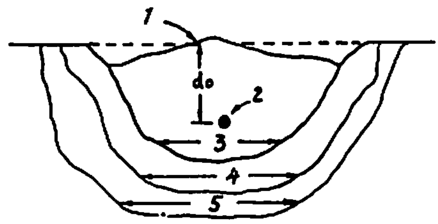

Fig. 2 Sectional view of fractured zone around blast crater.
1. Apparent crater
2. Spherical charge
3. True crater
4. Complete rupture
5. Extreme rupture

maximun and the broken rock size optimum, burial depth at this situation is defined as optimum burial depth d_0, and N is supposed as critical burial depth, i.e. the burial depth at which almost all explosion energy is consumed by rock medium, the blasting vibration causes elastic deformation in rock mass, and rock at the free face is just loosened in layers of bulges with fracture occurring. Thus the following expression could be used to show the relationship between explosives and rock medium:

$$N=EW^{1/3} \quad (1)$$

where N = the critical burial depth (meter) ;
W = charge weight (kilogram) ;
E = factor of strain energy, it is constant for a given rock-explosive coupling.

For the optimum burial depth d_0, expression (1) can be written in the following form :

$$d_0=\Delta EW^{1/3} \quad (2)$$

where Δ = the ratio of actual burial depth to critical burial depth.

Usually in practice one round of cratering test consists of several shots. In all of thes blasting operations the type of explosive, charge weight and rock property are kept unchanged, only the burial depth remains a variable. Thus other parametres can be determined by the actual crater volume measurement.

It is known that the shape of charges has notable influence on the blasting results (see Table 3).

Furthermore, Livingston expounded that with the geometrical shape of the charge changing, blasting process varies greatly, so does the blasting results. For example, when a column charge is used, almost all the energy in the form of explosion gas exerts its force on surroundings along the direction perpendicular to the hole axis, and only a very small portion of such energy can affect rocks at the ends of the column charge. However, when a spherical charge is detonated, such energy propagates in all directions from the charge center to the surroundings in an integral spherical radial form.

However, as C.W. Livingston further found that so long as length to diameter ratio is kept at or less than 6 : 1, the blasting mechanics and results would remain the same as that of real spherical charge. It is self-evident that this discovery greatly facilitates the

Table 3 Effect of different charge shapes on blasting results.

Parameter / Crater No.	Hole depth (m)	Hole depth (m)	Charge weigh (kg)	Burial depth (m)	Crater volume (m^3)	Radius of crater (m)	Lengthdiameter ratio of charge
No.1	11.4	1.2	4.5	1.07	2.03	1.74	27:1
No.2	6.7	1.2	4.5	0.72	1.09	1.46	15:1

Table 4 Cratering test results with CLH emulsion explosives in secondary of pillar stope blasting

Hole number	Hole depth (m)	Charge length (m)	Burial depth (m)	Stemming length (m)	B.D*	Crater volume (m^3)	q** (m^3/kg)	Visible crater depth (m)	Hole length remained (m)
1	3.00	0.45	2.78	2.55	0.85	0.25	0.06	0.13	2.87
2	3.50	0.45	3.27	3.04	/	/	/	/	/
3	1.31	0.45	1.09	0.86	0.33	1.21	0.27	0.97	0.34
4	2.60	0.42	2.39	2.18	0.73	0.12	0.03	0.41	2.19
5	1.93	0.43	1.72	1.50	0.53	1.03	0.23	0.81	1.12
6	1.60	0.45	1.38	1.15	0.42	1.79	0.40	0.60	1.00
7	2.20	0.46	1.97	1.74	0.60	0.67	0.15	0.19	2.01

Notes : * B. D. – Burial Depth to Critical Depth ratio.

** q– Rock/Ore broken by explosive of unit weight.

application of spherical charge in field blasting practice.

L.C. Lang brought forward a new concept of modified cratering blasting which supplemented and improved Livingston's theory. As he pointed, if a spherical charge is shot towards a free face such as the back of a drift or roof of any kind of underground excavations, a crater similar to ordinary one but inverted in shape will be formed. In this case, since the crater is upside-down, the gravitation force not only prevents nothing but promotes the break-off of rock in the fractured zone. There exists a stress zone beyond the fractured zone, where the rock can be further deteriorated and broken-off together with the next nearby cratering shot. Dependent on rock properties and geological formation, the total height of such upside-down crater may be many times larger than the optimum distance from the spherical charge to free face. Introducing this concept of upset crater into mining practice has lead to the VCR method developed.

2.2 Results of cratering test with CLH series emulsion explosives

Practice shows that blasting parameters must be determined based on the results of cratering test in situ. Therefore, with the particular rock properties and geological conditions at Fankou Lead and Zinc Mine, which type of CLH product and what mining blast parameters should be used—all these must also be determined by in situ cratering test.

Since rock and ore types and geological conditions are different between primary and secondary stopes, cratering tests ith CLH explosives were carried out in testing drifts near the stopes. 23 blast holes were shot in primary experimental stope and 22 blast holes in secondary stope (2 groups).

Horizontal blast holes were drilles with YQ-100 driller perpendicular to the walls. The hole size was 95-110 mm in diameter and 1.5 meters from drift floor. For different burial depth, hole length varied between 1.0-3.5 meters. After charging, the holes were stemmed up to the mouth. The outer diameter of charge bag was 95 mm. and the charge for each hole was 4.5 kg with a 200 g cast primer (RDX : TNT = 1 : 1). The primer and charge were detonated with detonating fuse and blasting cap to ensure complete explosion, and the holes were shot separately. After being cleaned, the craters were measured for such parameters as visible depth, diameter and volume. Ore rock broken and cleaned out was classified by screening and then weighed.

The cratering test results show that under particular geological conditions the blasting mechanics and breaking results are quite defferent among explosives with different characteristics. It was found that CLH-2 explosive was fairly suitable for Fankou Mine. Based on the previous tests, further extensive cratering tests with CLH-2 explosive were carried out in drifts adjacent to the two experimental stopes. The results are shown in Tables 4 and 5, and the relationship between the unit volume ore broken by unit explosive (*V/Q*) and burial depth ratio (Δ) is expressed as curves in Fig. 3.

It can be easily seen from Fig. 3 that despite the

Table 5 Cratering test results with CLH emulsion explosives in primary or room stope blasting.

Hole number	Deto. velocity m/sec	Density g/cm³	Weight percharge bag (kg)	Burial depth (m)	Crater parameters Dia. (m)	Crater parameters Visible depth (m)	Crater parameters Volume (m³)	Blasting effect L.T.50mm (%)	Blasting effect 50-150mm (%)	Blasting effect 150-300mm (%)	Blasting effect G.T.300mm (%)
8	4855	1.43	4.5	1.03	3.50	1.02	2.40	35.06	31.89	17.1	15.95
23	4855	1.43	4.5	1.40	2.05	1.48	4.29	49.2	22.6	17.6	10.6
4	4855	1.43	4.5	1.80	2.45	1.13	2.96	/	/	/	/
21	4855	1.43	4.5	2.31	2.61	0.90	2.00	34.2	23.84	20.89	21.2
7	4855	1.43	4.5	2.79	1.90	0.52	0.58	25.9	27.6	32.9	13.55
19	4855	1.43	4.5	2.98	0.40	0.20	0.15	46.0	44.8	9.2	/
28*	3000	1.00	4.5	1.660				37.92	27.63	25.98	8.47

*The hole No 28 was charged with rock breaking explosive No 2.

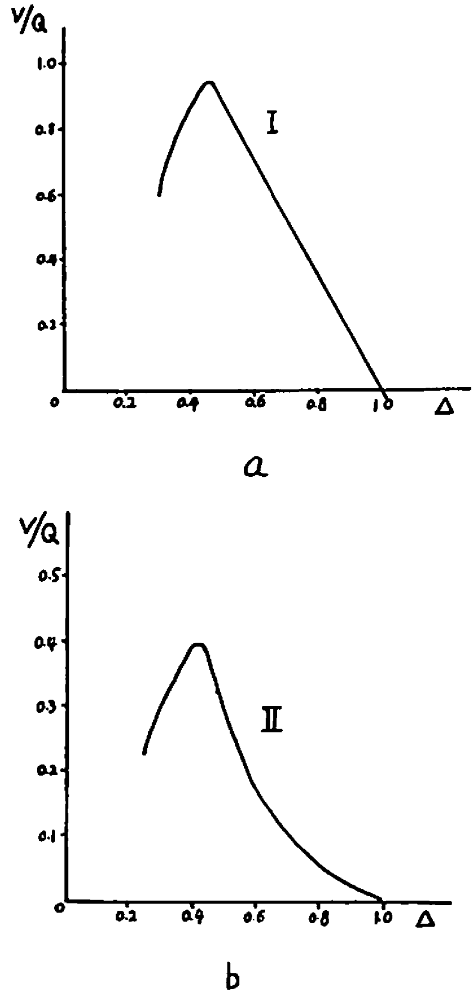

Fig. 3 Relationship between unit volume ore broken by unit explosive (V/Q) and burial depth ratio (Δ).
a-achieved in primary stope
b-achieved in secondary stope

difference in crater parameters between stopes and in the height of two curves, the curves in Fig. 3 show similar forms.

Based on the results aforementioned, parameters for different mining stopes were worked out, as shown in Table 6.

3. Practical Technique and Effect Analysis

3.1 Rock/ore properties in experimental stopes

The two experimental stopes are located respectively in secondary stope No.3-4 of -80 m level in Shiling area, and primary stope No.1 of -160 m level in Jinshiling area, Fankou Mine, Different rock properties and geological conditions were involved.

Table 6 Parameters form cratering tests (for CLH series emulsion explosives).

Experimental stopes	Critical burial depth (m)	Optimum burial depth (m)	E^*	Parameters at the optimum burial depth				
				Crater radius (m)	Visible depth (m)	Crater volume (m³)	B.D** ratio	Power factor (kg/m³)
Shiling-80	3.27	1.38	1.98		0.60	1.97	0.42	0.40
Jinxingling-160	2.98	1.40	1.78	1.45	1.54	4.29	0.47	1.11

Notes : * Strain energy factor

** Burial depth

Table 7 Physico-mechanical properties of rock/ore in Shiling stope.

Ore/rock types	Volume weigh (g/cm³)	Transmission velocity of p-wave in sample (m/sec)	Transmission velocity of p-wave in rock mass (m/sec)	Velocity of S-wave (m/sec)	Compressive strength (kg/cm²)	Tensile strength (kg/cm²)	Shearing strength (kg/cm²)	Poisson ratio	
								statical	dynamical
Ore	4.31	6022	2995	4490	1561 (14-18)	62	120	0.26	0.36
Limestone	2.82	5824	2800	3690	1502 (10-12)	54	150	0.19	0.13

Ore in Shiling secondary stope is dense, massive high grade ($P_b+Z_n=26.41\%$) pyritic lead-zine ore with total sulphur up to 33.3%. Mined ore from this stope has a tendency of spontaneous heating. The ore and its surrounding rock are fairly competent (f=8-10) and their blastabilities range from "medium-difficult" to "very difficult." The ore-rock contact is distinct, with striped nodular limestone as foot wall and spotty limestone as hanging wall. The foot wall is in contact with a big fault named "F3", dipping at an angle of 70°—90°, which is the main fault in this area, dominating the geological structure. The stope has a width of 8 meters, a length of about 38 meters and ore reserve totaling 45, 499 tons. Main rock/ore physico-mechanical properties are listed in Table 7.

Jinxingling stope is located at both ends of ore body "Ji-2" of Fankou Mine, its upper part is loosened due to oxidizing and leaching. The ore and surrounding rock throughout the orebody are medium competent. Part of the hanging wall in No 1 stoping section is adjacent to fault F4, and there exists a fractured zone at the middle of this stope, where the ore body is considerably fractured. Ore/rock physico-mechanical properties of this stope are shown below in Table 8.

3.2 Production Blast

VCR method is characterized by drilling holes in one step followed by repeated blasting operations, i. e. charging-shooting circle will repeat several times in each hole. Therefore proper selection of hole pattern, charge loading structure and stemming length, etc. is of vital importance to eusure satisfactory blasting results.

The spherical charge blast operation in VCR mining includes hole-measuring, bottom-plugging, charging, stemming, ignite circuit connecting and igniting. Based on the parameters obtained from a series of cratering tests, the drill pattern, single deck charging structure and detonationg circuit were determined, as shown in Fig. 4, 5 and 6.

5, 10 and 12.5 kg charge bags, 150 mm in diameter, were used in the experimental stopes. The charges were detonated with the help of cast TNT-RDX primer (200 grams, TNT : RDX=1 : 1). Double

Table 8 Physico-mechanical properties of ore in Jinxingling stope

Compressive strength (kg/cm²)	887
Poisson ratio	0.274
P-wave velocity (m/sec)	5513.42
Volume weight (g/cm³)	3.92

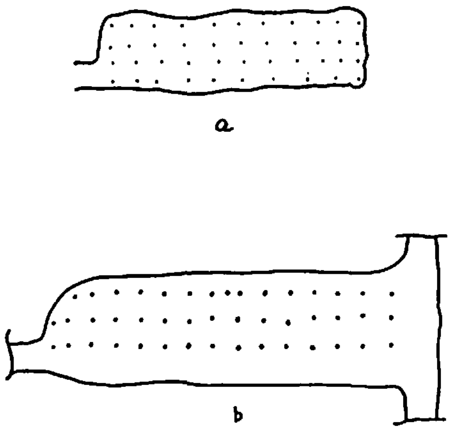

Fig. 4 Drill pattern.
a-for Jinxingling−160m level primary stope
b-for Shiling−80m level secondary stope

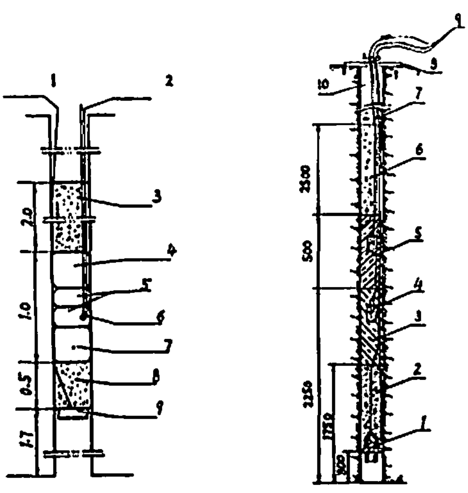

Fig. 5 Single deck charging structure.
a-for Jinxingling −160 level primary stope
b-for Shiling −80m level secondary stope
a ; 1—nylon rope 2—detonating cord
3—sand stemming 4—10 kg charge bag
5—5 kg charge bag 6—primer
7—10 kg charge bag 8—sand stemming
9—cement plug
b ; 1—plug 2—sand
3—12.5kg charge bag 4—pimer
5—12.5kg charge bag 6—sand
7—detonating cord 8—wood stick for hanging
9—detonating tube 10—drill hole

igniting system, i. e. plastic detonating tube in combination with detonating cord were employed to eusure a reliable ignition. The whole igniting circuit was capped with two instant electrical detonators.

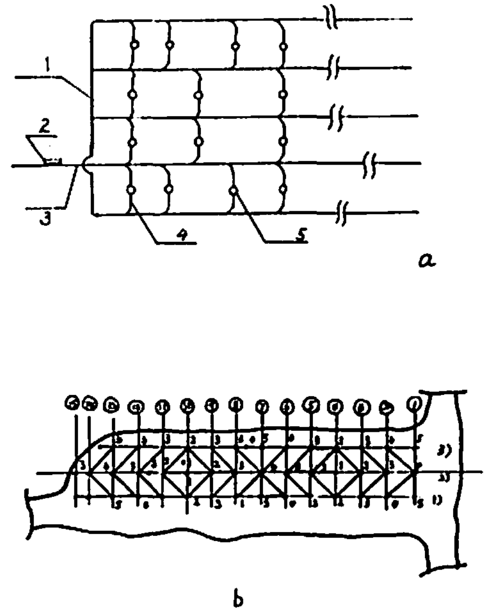

Fig. 6 Igniting circuit.
a−for Jinxingling −160m level primary stope
b−for Shiling −80m level secondary stope
6a : 1−branch detonating cord
2−electrical detonator
3−main detonatingcord 4−detonating tube 5−drill hole
b : 1−1st row
2−2nd row
3−3rd row

Before blasting, the hole depth should be measured. Afterwards holes should be plugged with wooden or cement plugs and stemmed to the optimum burial depth. In the mean-time igniting system is assembled i. e. the primers are capped, and then the capped primers connected with detonating cord or detonating tube. Then, one charge bag or several charge bags connected with igniting system by inserting the primer into the bag (or bags) is loaded to the proper position in the hole. Finally, holes are stemmed and the whole igniting system is hooked-up for final igniting. Generally, blasting operation in VCR method is simple, so long as the data of cratering test are reliable, a satisfactory blasting effect is usually obtained.

It should be mentioned that the upper stemming is very important. Under-stemming may cause collar damage of even damage to the back of drilling opening, leading to an unsafe situation whereas

Table 10 Blasting results in experimental stopes.

Stopes	Slice sequence	Quantity of holes	Amount of charge (kg)	Slice thickness (m)	Ore blasted (t)	Powder factor (kg/t)
Jinxingling-160m level primary stope	1	44	1320	3.12	2746	0.40
	2	46	1370	3.54	3338	0.43
	3	3	1335	4.06	3446	0.39
	4	43	1200	3.85	3147	0.38
	5	45	1515	4.08	3872	0.39
	6	45	1515	4.14	3832	0.40
	top slice		7200	18.45	17357	0.41
	summary		15455	41.24	37738	0.40
Shiling-80m level secondary stope	1	37	1110	3.80	3900	0.28
	2	42	1050	3.90	4300	0.24
	3	43	1075	3.92	4600	0.23
	4	45	1125	3.75	4500	0.25
	5	42	1075	3.93	4800	0.22
	6	37	788	3.13	3000	0.26
	top slice	36	2250	9.60	8400	0.27
	summary		8473	32.03	33500	0.25
	Total		23928	73.27	71238	0.33

over-stem-ming may reduce the thickness of the broken ore slice.

3.3 Blasting results

A total of 25.5 tons of CLH-2 emulsion explosive was consumed in 16 rounds of single slice blast and 2 rounds of combined blast with column charge and partially spherical charge at the two experimental stopes aforementioned.

Blasting results are given in Table 10.

4. Conclusion

From mining practice in Fankou Lead-Zinc Mine with CLH series emulsion explosives, products of high density, high detonating velocity and high strength, following conclusions can be drawn.

a. CLH series explosives featuring high density, high detonating velocity and high strength are very effective for VCR mining.

b. Since cratering theory is the foundation of VCR mining method and cratering test in site is a key to realization of this method, due attention should be directed to this basic work. Through a series of cratering tests all parameters can be established for guiding VCR operating blasting.

Reference

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2) L.C.Lang : The Aus. I.M.M. Melbourne Branch, Rock Breaking Symposium, Nov. 1978, 115-124.
3) L.C. Lang : E/MJ, 1976, Vol. 177, No. 5, 98-101.