EVALUATION OF AN EXHAUST FACE VENTILATION SYSTEM FOR 20-FOOT EXTENDED CUT USING PHYSICAL SCALED MODEL

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ABSTRACT

The face ventilation plans for extended cut must be submit by the Coal Mining Company to the Mine Safety and Health Administration (MSHA) for evaluation and approval. This

evaluation process could be enhanced by having the opportunity to perform an experimental and a numerical study of the proposed ventilation arrangements. These studies could provide a clear determination and adequateness of the ventilation in the face area.

In this paper, the authors will present and discuss the data collected during the experimental study of face ventilation scenarios using a scaled physical model (1:15), equipped with in-house designed and developed Particle Image Velocimetry (PIV) system. The face ventilation arrangements evaluated in this paper are typical of the plans submitted to MSHA for approval by Eastern Kentucky coal companies that utilize continuous mining machines not equipped with scrubbers or mechanical face ventilation enhancing devices.

INTRODUCTION

Coal mine face ventilation plans, submitted to the Mine Safety and Health Administration by the Coal Mining Company for approval, must be evaluated prior to implementation. Critical factors such as the sweep of the face, workers exposure to dust, and compliance with health and safety regulations pertaining to acceptable methane concentration levels must be determined. To be able to evaluate these factors properly, new sophisticated engineering tools (methods) are needed. First is an experimental method using full or scaled physical modeling. However, a full scale modeling is very expensive. Second is a Computational Fluid Dynamics (CFD) technique, which can be potentially applied. This method still required more validations to be able to be utilized with confidence [5], [8], and [9].

The CFD is a new and rapidly developing numerical technique by which complex fluid flow problems can be solved on a digital computer. This technique can be an attractive approach to predict, evaluate, and design proper mine face ventilation systems. However, to develop confidence in the accuracy of CFD the verification between numerical and experimental results are required for validation purposes. During the last two and half years such a validation study, funded by NIOSH Grant #R01 CCR415822, are being carried out in the Department of Mining Engineering, University of Kentucky [8], [9].

As the part of this project the authors designed and developed a scaled physical model of the face ventilation systems (see Figure 1). This model has been shown to be valid/acceptable tool for a scaled study of the face ventilation systems, by validation test performed in the full-scale testing facilities at the NIOSH Pittsburgh Research Center, in June 2002.

Figure 1. The physical model of the mine face area.

Figure 2 shows measured two-dimensional flow distribution (velocity vectors) in scaled and full size testing gallery, for comparison purposes. After this encouraging result the authors are confident that scaled physical models could be used for validation of the face ventilation plans and help in the approval process.

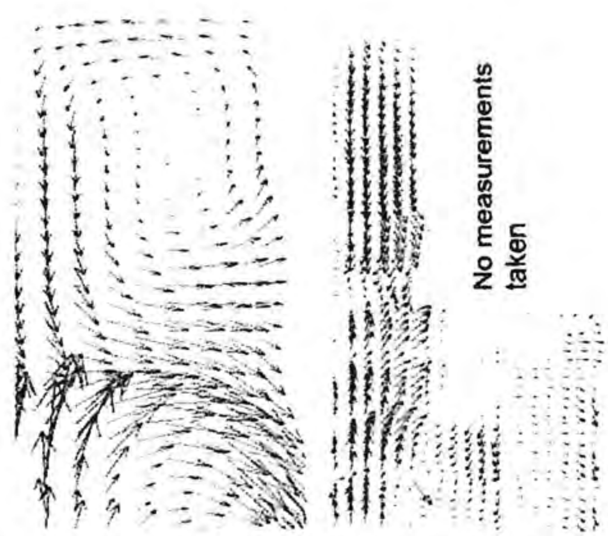

Figure 2. Comparison between scaled (model on left) and full-scale (NIOSH on right) flows.

NEED FOR FACE VENTILATION PLANS VALIDATION TOOLS

Blowing face ventilation systems with scrubber-equipped continuous mining machine are commonly used in the U.S. underground coal-mines for extended cuts. This type of the face ventilation system has shown be the most efficient if all components of the system are working properly. However, in cases of scrubber failure, continuous mining machine not being equipped with scrubber or with other mechanical face ventilation enhancing devices, the recommended blowing ventilation system must be replaced by the exhaust system.

Usually, when circumstances like those described above occur, the typical plans for exhaust face ventilation are submitted to MSHA for approval, see Figure 3. The characteristics parameters of these plans are as follows: (1) exhausting face ventilation systems; (2) cut depths of 20 feet; (3) the number of box (sump) cuts and slab cuts (cutting sequences) range from 2 to 4, (4) a line curtain air quantity of 2.1 m3/s (4,300 cfm), and (5) the cut one will always be on the curtain side.

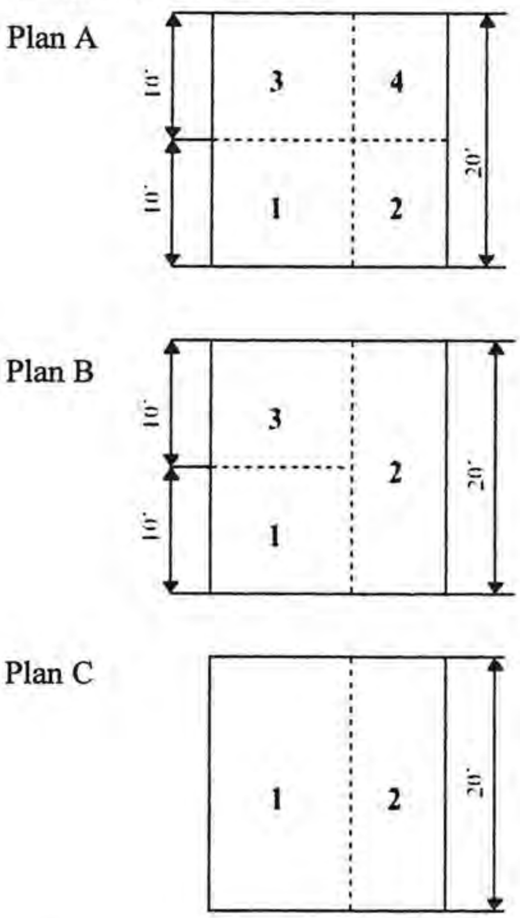

Figure 3. Three typical exhaust face ventilation arrangements for 6.1 m (20 ft) deep cuts.

Applying Plan "A" the authors have attempted to demonstrate how the experimental study, using scaled model equipped with the Particle Image Velocimetry system, can be useful to determine the flow distribution and evaluate control devices used for ventilation enhancements in the face area.

SCALED PHYSICAL MODEL FOR FACE VENTILATION PLANS VALIDATION

Description of the Scaled Physical Model

A 1:15 scaled model of a 2.1 m (7 ft) high, 6.1 m (20 ft) wide mine face area was designed and built out of transparent Plexiglas (see Figure 1). Scaling of the geometry was performed using dimensional analysis based on the Reynolds Number, Re=UL/ν, where U and L are the velocity at the brattice line mouth and width of the inflow (distance between the brattice line and entry rib), respectively. The model consists of three significant parts. First, the middle section, which represents an ordinary mining entry with a partition (brattice line), divides the entry into a narrow 2 feet wide intake and an 18 feet wide return airways. Second is the working section, which represents a face area, where movable Plexiglas walls can be used to replicate many different ventilation configurations such as box cut or slab cut arrangements with brattice setback distances varying from zero to 18.3 m (60 ft). Third is the intake/return section, where the ventilation system can be arranged as either blowing or exhausting by changing the fan location. During this particular study, the model was setup as an exhaust ventilation system with a setback distance of 6.1 m (20 ft), see Figure 3.

Description of the Particle Image Velocimetry System

The PIV technique was proposed for measurement of instantaneous velocity fields of the time dependent flows in the scaled model. PIV is an optical technique for measuring two velocity components over an extended two-dimensional area. Due to relatively high air velocity in the model, a pulse laser system was required. To perform these measurements, tracer particles must be added to the flow field; highly reflective ~5 μm talc particles were used in the experiments discussed herein. The laser-light sheet illuminates these particles twice within a short time-interval. The reflected (scattered) light from each laser pulse is sequentially imaged by a CCD camera, and recorded digitally to a computer using a frame grabber. To create one averaged velocity field for a particular scenario, approximately fifty pairs of instantaneous images of velocity fields are recorded for digital analysis.

The schematic of the integrated PIV system used in this study, seen in Figure 4, is comprised of the followir components: (1) laser and light sheet optics, (2) ir capture system, (3) synchronizer, (4) smoke generator, and (5) image analysis and display. Th double pulsed 50 mJ Nd:YAG laser and talc se particles whose motions are recorded Megaplus 10-bit CCD camera. Images using an Epix PIXCI-D digital frame grabber/camera combination has a d allows two images to be acquired back-to-back within an extremely small time (~10 μs). Timing is controlled via a Taitech DG-100 timing control unit, which is monitored using an oscilloscope. This system is discussed in more in Turner, Wala, and Jacob paper [7].

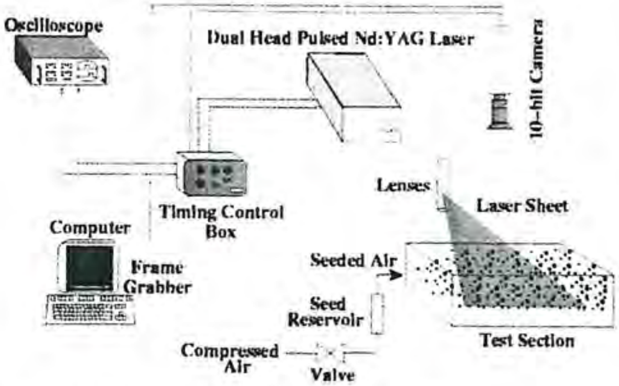

Figure 4. Schematic of the integrated PIV system.

Experimental Data from Scale Modeling

By utilizing the physical model of the face ventilation system (described above) numbers of different mining scenarios, representing coal mining process, using continuous miners with exhaust face ventilation system for 6.1 m (20 ft) depth extended cuts, were tested. For this particular study, as mentioned before, the 4 cut sequence mining operation was adopted.

- SCENARIO #1 - "NO EQUIPMENT IN THE FACE AREA"

To be able to show the general flow behavior (distribution) in the face area for the exhaust ventilation system, flow measurements were taken at the middle plane of the entry with no equipment. Figure 5a and 5b shows the velocity vectors in the face area just after the first cut and third cut were completed, respectively. As can be seen from these figures, most of the air is turning immediately back behind the curtain and only a limited amount is flowing toward the face. Nonetheless, whatever is getting into the face area creates large vorticity.

- SCENARIO #2 – "EQUIPMENT IN THE FACE AREA"

A scaled model of a continuous miner, simulating Joy Model 14 CM/10, was placed in the face area. Four different locations for the continuous miner, depending on cutting sequence, were investigated. These locations were as follows:

- halfway of the number 3 cut,
- end of the number 3 cut,
- beginning of the number 4 cut, and
- an end of the number 4 cut.

For all four arrangements the line curtain setback was 6.1 m (20 ft) and carries quantity of air equal 2.1m^3/s (4,300 cfm). Figures 6, 7, 8, and 9 shows the velocity vectors measured at the plane above the continuous miner, respectively, to the list above. Again, as can be see from all these figures, only a limited amount of air reach the location were is needed for gas dilution and dust removal. This means that at the face where the cutting head of the continuous miner is located there is a lack of air. Therefore, in such a case there is a question what can be done or what is being done to improve these situations. In the last fifteen years the National Institute of Occupational Safety and Health (NIOSH), and previously by the US Bureau of Mines (USBM) [1], [3], and [6], has conducted extensive research to determine and develop the most effective ventilation schemes for extended cut mining methods. Several ventilation enhancing devices including; (1) continuous miners with machine-mounted scrubbers, (2) extendable line curtains/flexible tubings, (3) jet fans, (4) sprayfans, and (5) a combination of these devices have been designed, tested and implemented [2], [3].

- SCENARIO #3 - "EQUIPMENT WITH VENTILATION ENCHANCING CONTROL DEVICE"

To be able to show changes/enhancement in the flow distribution in the face area for above tested scenarios, the authors applied the well known practice of extendable curtain, see Figure 10. The mining arrangements for this scenario are almost identical as for Scenario #2, with exception that simple extendable curtain forces more air to cross the cutting head of the continuous miner. The following four figures 11, 12, 13, and 14 shows the velocity vectors (flow distribution) for arrangements as described in Scenario #2 with the extendable curtain in place.

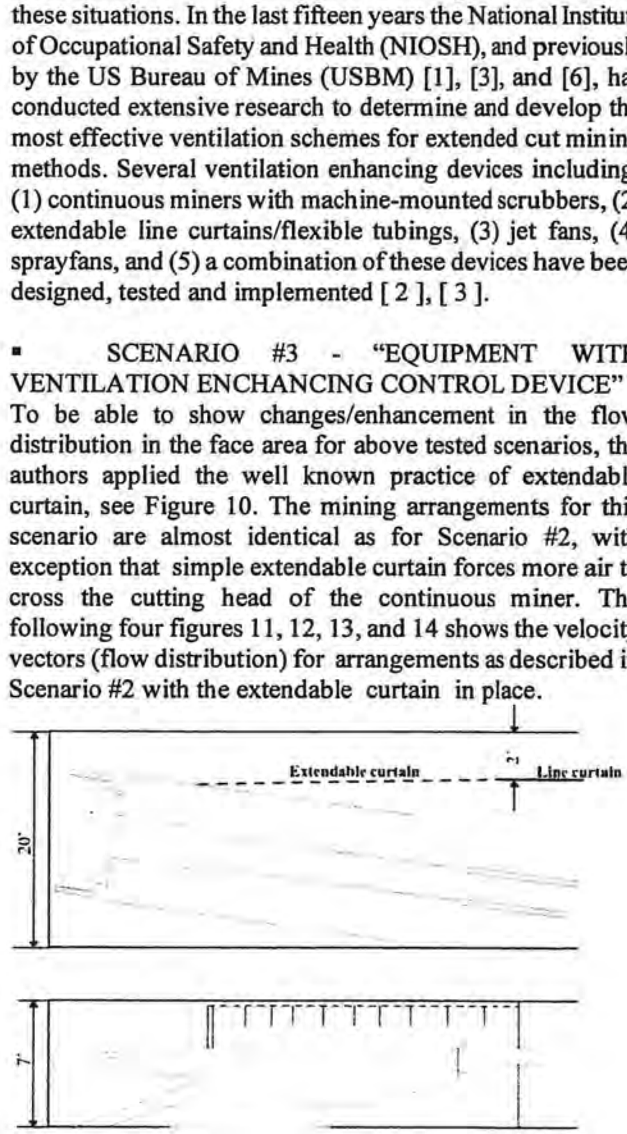

Figure 10. Schematic of the miner model with extendable curtain.

CONCLUSIONS

1. According to the objective of this paper, the authors using the existing scaled model of the face ventilation systems were able to demonstrate how useful this model can be for validation of the face ventilation plans and help in approval process.

2. Based on this study the performance of the exhaust face

ventilation system under Plan "A", (see Figure 3), for 4 cut sequence scenario with 20-foot exhaust curtain setback is not very promising. Some mines have obtained MSHA approval for such scenario. None of these mines have significant methane gas to be controlled.

3. The last part of the study shows how using relatively simple and inexpensive type of ventilation enhancement, by applying 10 feet extendable curtain, the ventilation in the face area could be improved.

ACKNOWLEDGEMENT

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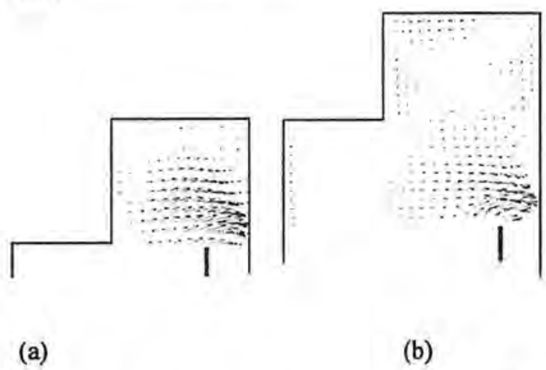

Figure 5. Velocity field with no miner. (a) 1st cut (b) 3rd cut.

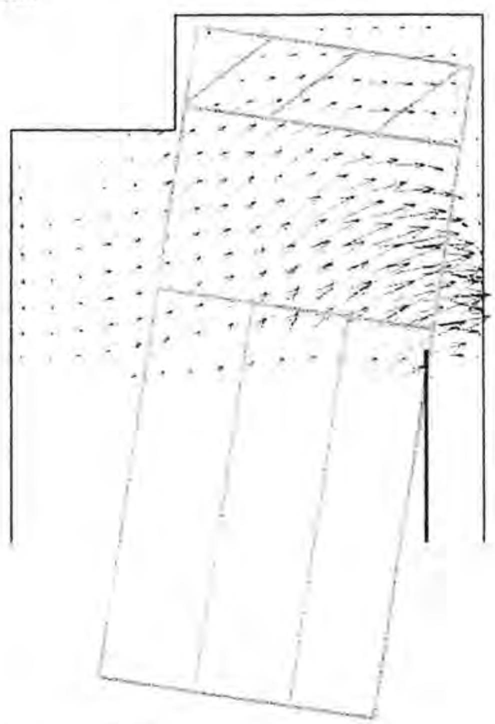

Figure 6: Halfway of the number 3 cut.

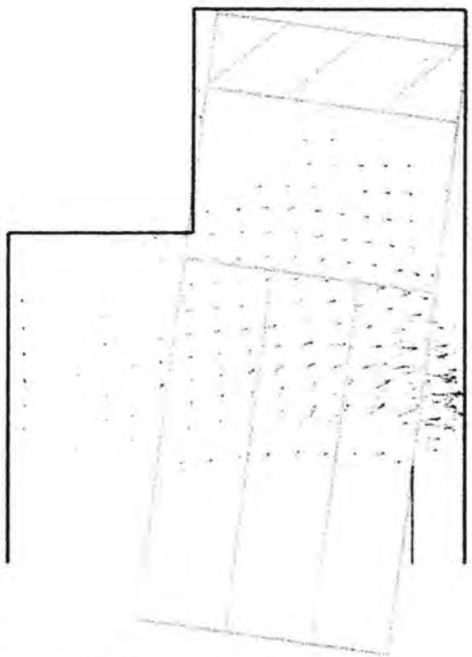

Figure 7: End of the number 3 cut.

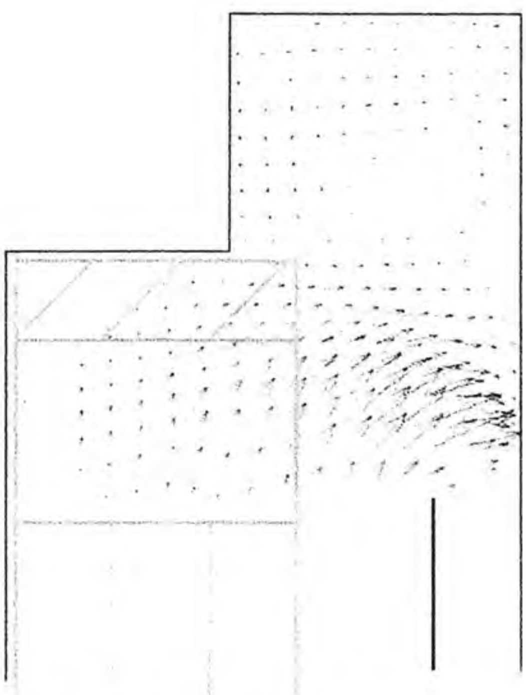

Figure 8: Start of the number 4 cut.

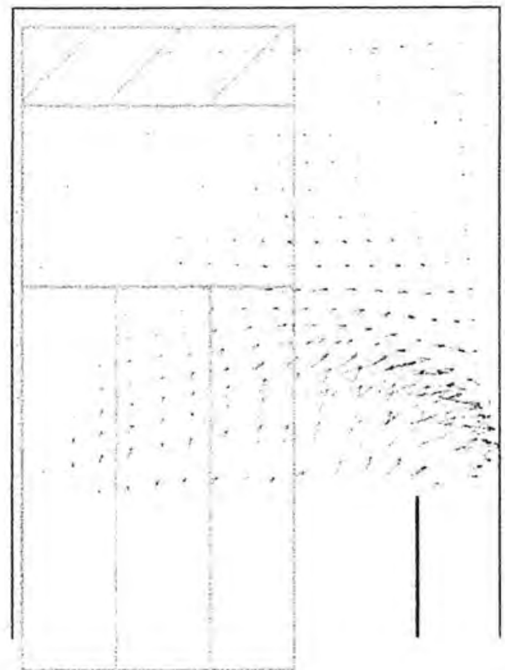

Figure 9: End of the number 4 cut.

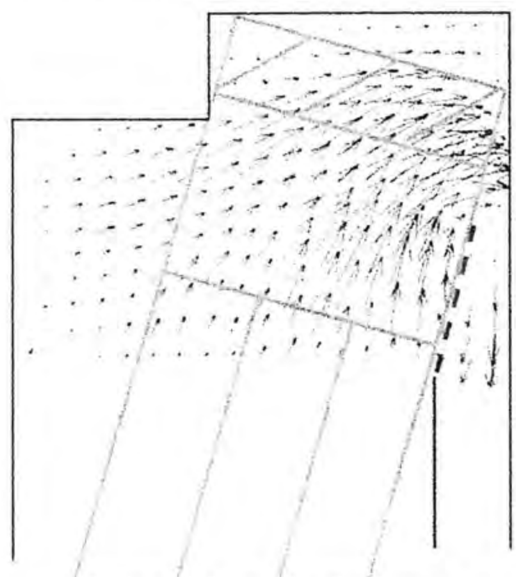

Figure 11: Start of the number 3 cut with extendable curtatin.

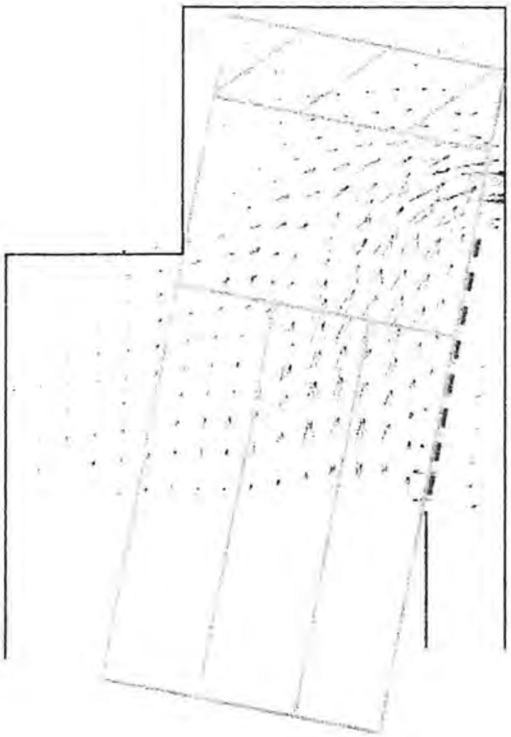

Figure 12: End of the number 3 cut with extendable curtain.

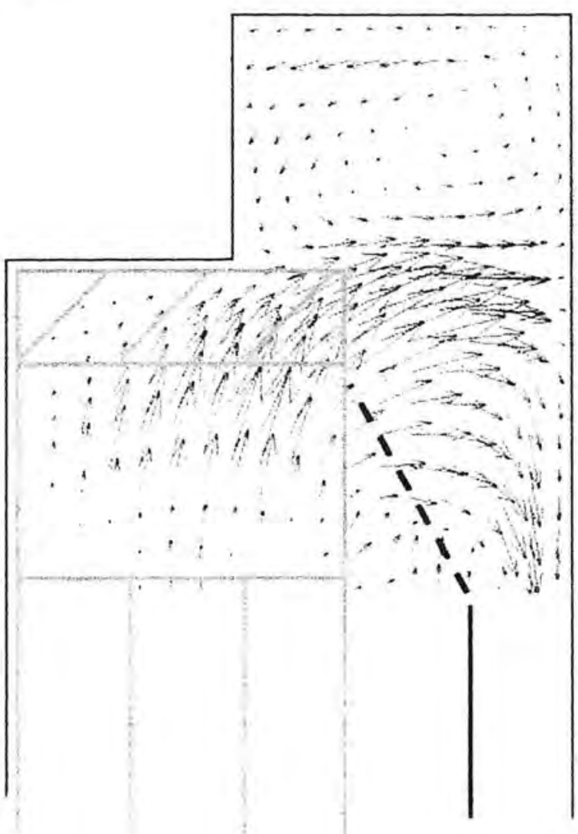

Figure 13: Start of number 4 cut with extendable curtain.

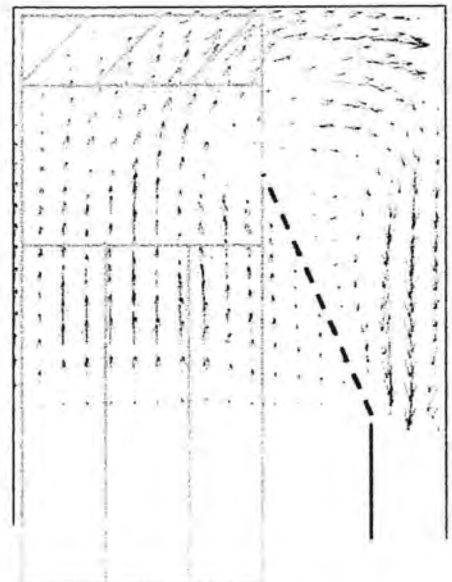

Figure 14: End of the number 4 cut with extendable curtain.