Studies of Controlled Recirculation Using CO_2 Gas Injection: *Laboratory and Simulation Results*

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Outline

- Introduction
- Recirculation
- Laboratory Experiment
- Numerical Simulations
- Conclusions and Recommendations

Introduction

- As underground coal mines develop deeper and more extensive workings, the demand of ventilation is substantially increased.

- It is frequently necessary to upgrade the ventilation system to maintain adequate airflow in working areas.

- Mostly commonly, ventilation is enhanced by upgrading existing surface fans, adding new surface fans, and developing new shafts.

- Booster fans represent an alternative to installing new surface fans or developing new ventilation shafts.

What is a Booster fan?

- It is a ventilation device installed in series with a main surface fan and used to boost the pressure of the air current passing through.
- It operates in combination with the main fan(s), even if physically separated.
- It's purpose is to overcome a fraction of mine's frictional losses in just like surface fans overcome all losses within a mine.
- The fan is installed in a permanent stopping and equipped with airlock doors, interlocking devices and monitoring systems.
- It handles airflow of either one or several districts of the mine.

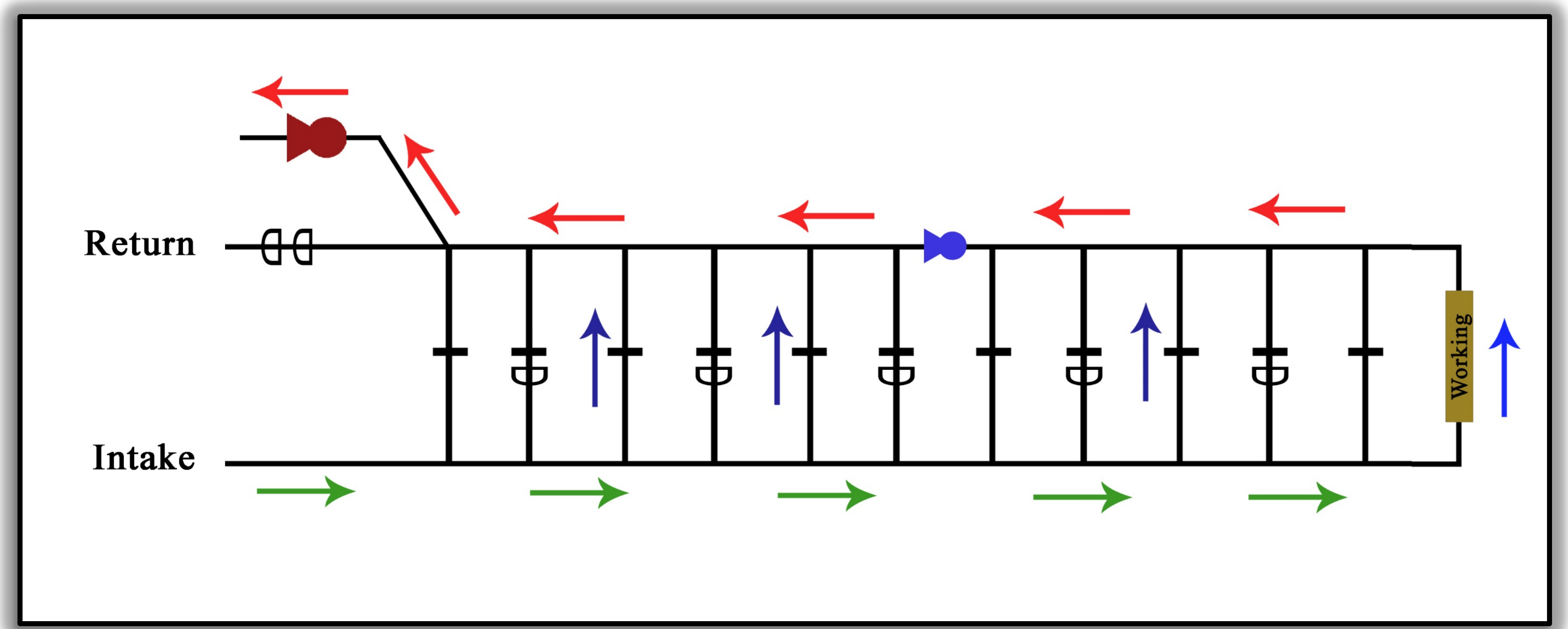
Booster fan Installations

Ventilation Doors

What is Recirculation?

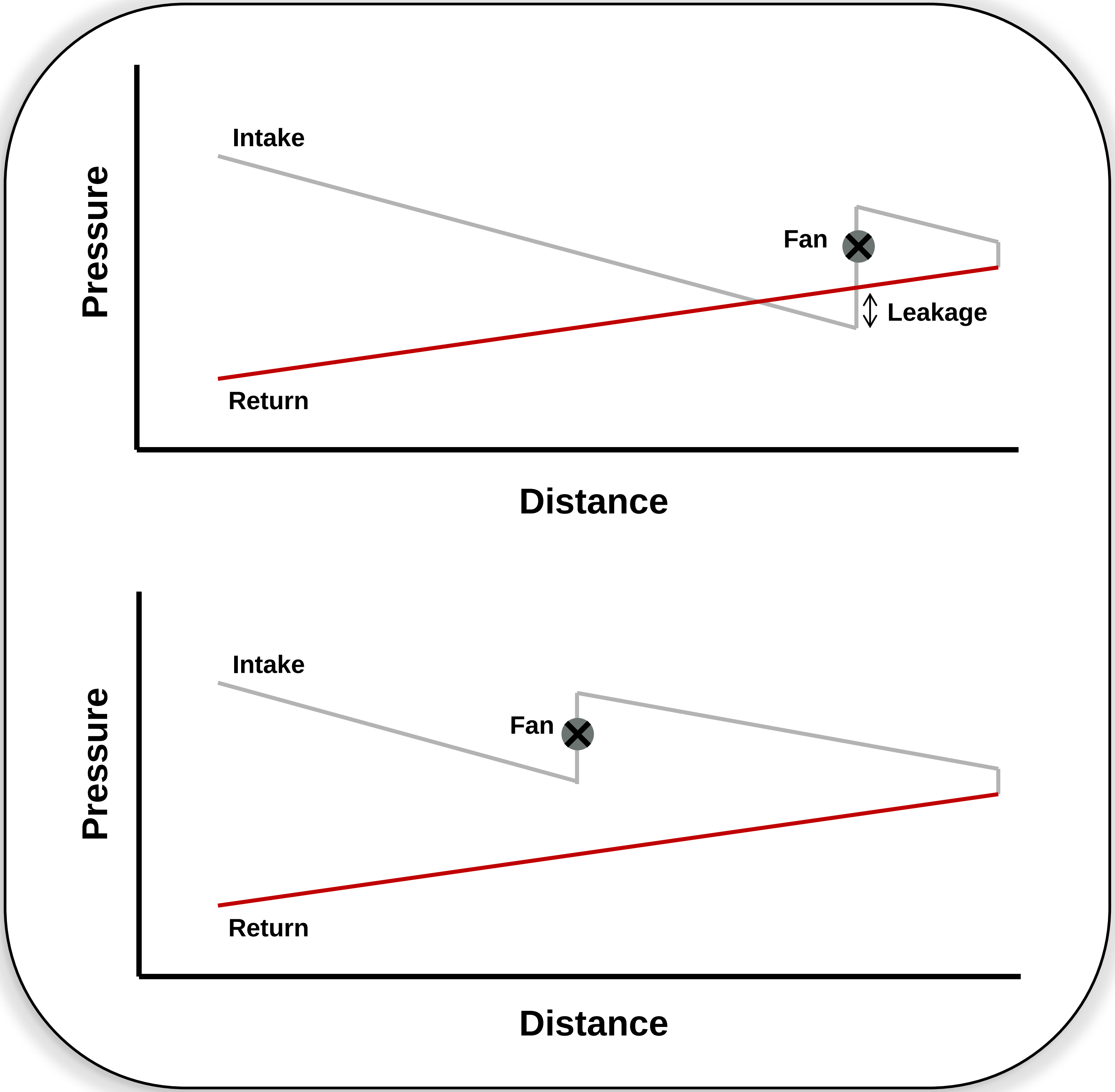
- Recirculation is an issue associated with the utilization of booster fans.
- It occurs when the pressure in the return airway is higher than the pressure in the intake airway, causing the return air to leak from return to the intake.
- It occurs in systems with multiple fans, when the booster fan is not sited or sized properly.

Improper sizing and position causes Recirculation



Schematic showing general mine heading with multiple stoppings

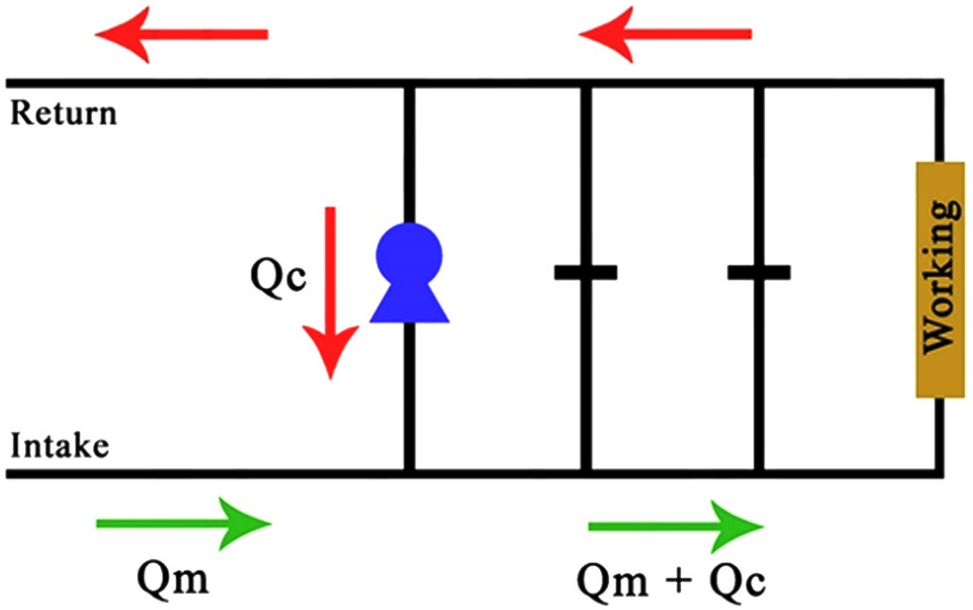
Improper sizing and position causes Recirculation



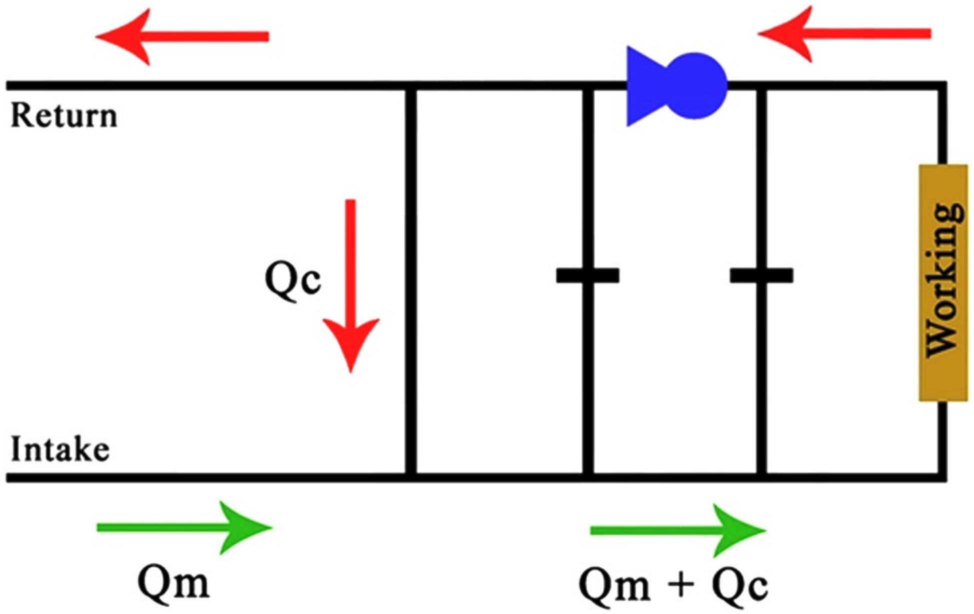
Controlled Recirculation

- In controlled recirculation, a portion of the return air is purposely mixed with the intake air.
- The mixture of air is directed to a working district while the quantity of air is closely monitored and managed.
- It can increase the capacity of the ventilation system by increasing the quantity and air velocity near the production areas.

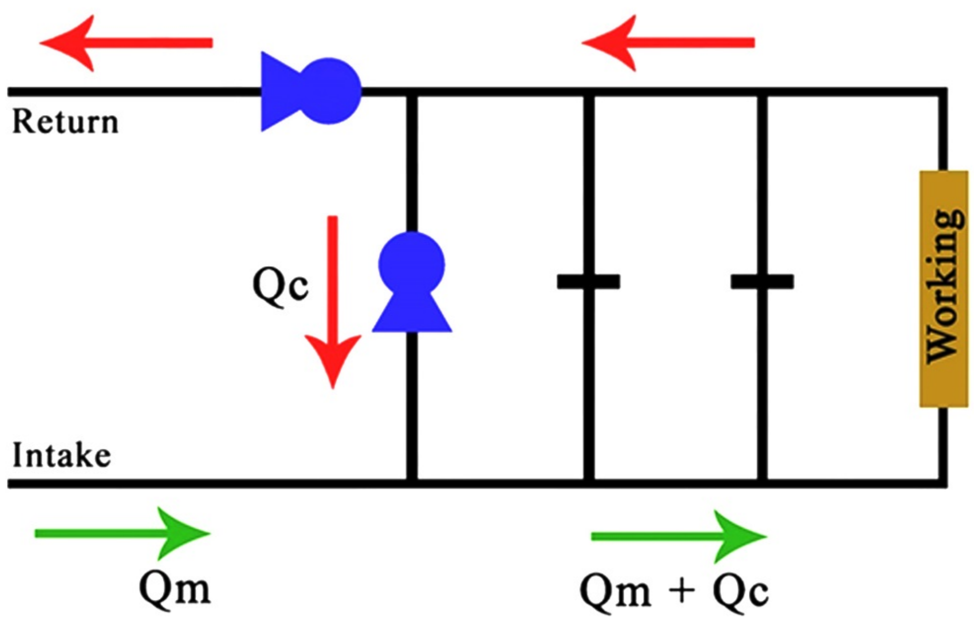
Controlled Recirculation Types



CROSS-CUT RECIRCULATION



IN-LINE RECIRCULATION



COMBINED RECIRCULATION

Recirculation Fraction:

$Rf = Qc / (Qm+Qc)$

Booster fans in US Coal Mines

1900

1920

- Initial regulations regarding the safety and use came in the 1920s.
- They were influenced by several accidents, fires and explosions related to their use.
- Research was performed to study booster and auxiliary fans for the purpose of formulating recommendations

1928

- In December 1928, the Mine Safety Board recommended that auxiliary fans or blowers should not be used in coal mines as a substitute for methods of regular and continuous coursing of the air to every face

1937

- Mine Safety Board suggested only where it is not practical to put down a new shaft and when the air pressure required would be so high as to prevent proper operation of underground ventilating doors.
- The reason was recirculation of mine air was found in most investigated installations.

1969

- The Federal Coal Mine Health and Safety Act of 1969 (Coal Act) did not specifically prohibit the use of booster fans

1992

- The final rule in 1992 still does not permit the use of booster fans.
- Reasons cited by MSHA were approval criteria, established industry practice and several safety concerns associated with such issues as recirculation, fires, fan control, noise and dust..

2013

Design of Experiment

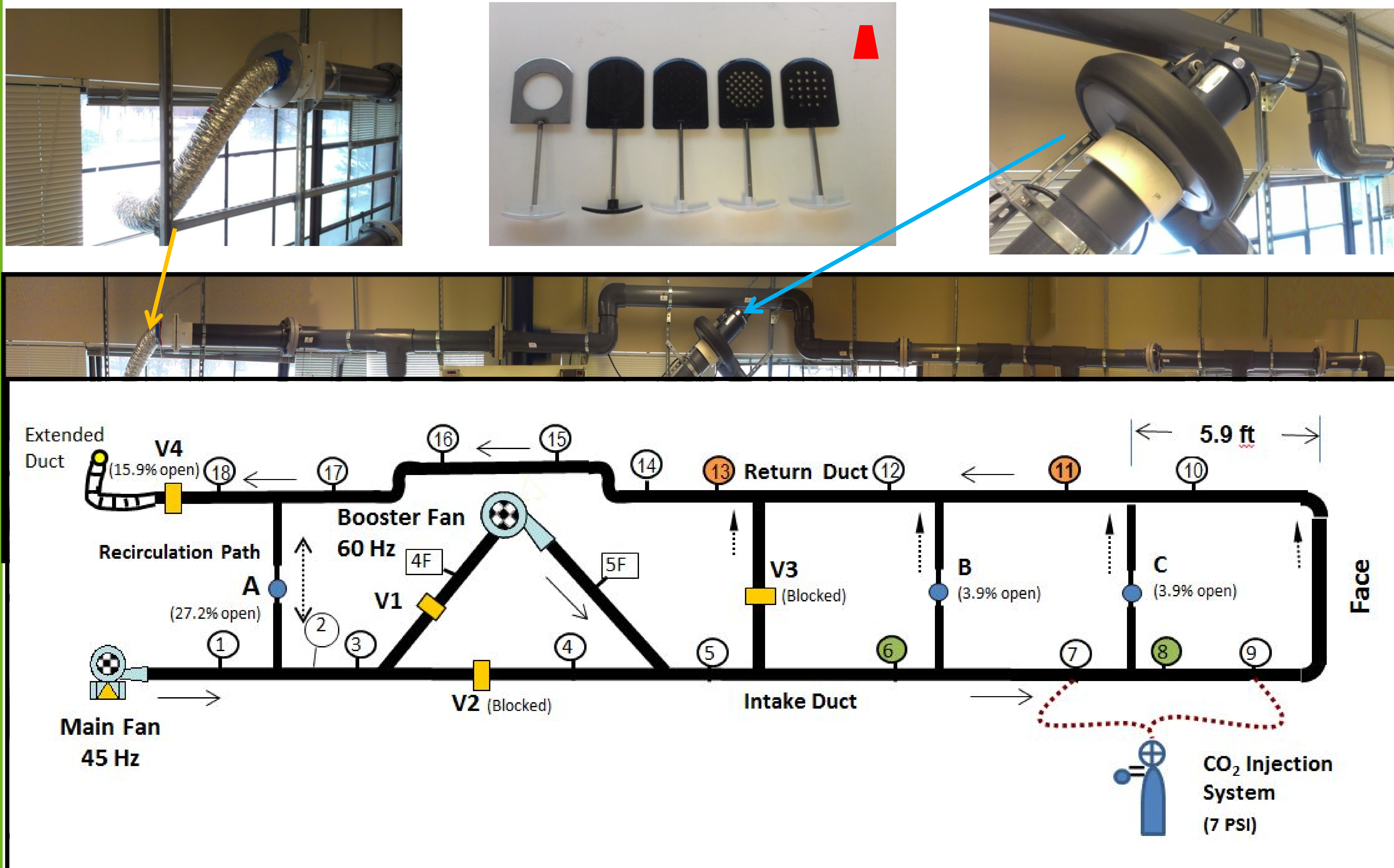
University of Utah Laboratory Model

- Active coal mine ventilation systems are complex and dynamic. It is difficult to conduct accurate and detailed field experiments
- Field experiments to study the characteristics of recirculation in an active U.S. coal mine is not possible
- Experimental conditions could be well controlled and variables could be systematically modified
- The laboratory coal mine ventilation model was designed based on the fluid mechanics principle of similitude

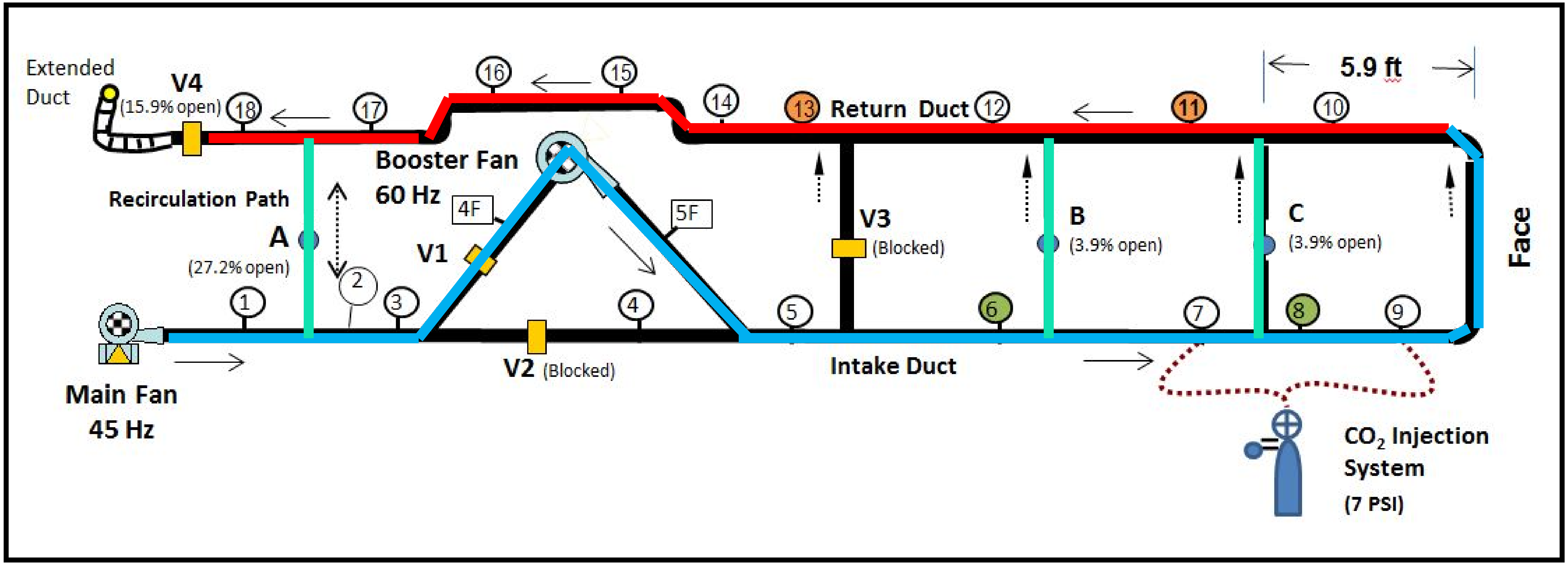
University of Utah Laboratory Model

- To determine the effect of booster fans on recirculation, a scaled model of a coal mine was developed
- The model simulates a two fan ventilation system. The fans are equipped with variable speed drives
- The model consists of a 5.75-in. diameter pipe network in a ‘U’ shape, two centrifugal fans, two gas injection points, and five gate valves that can be used to simulate different types of stoppings
- Several experiments were conducted under various flow and recirculation conditions
- One of the experiments is discussed here

University of Utah Laboratory Model

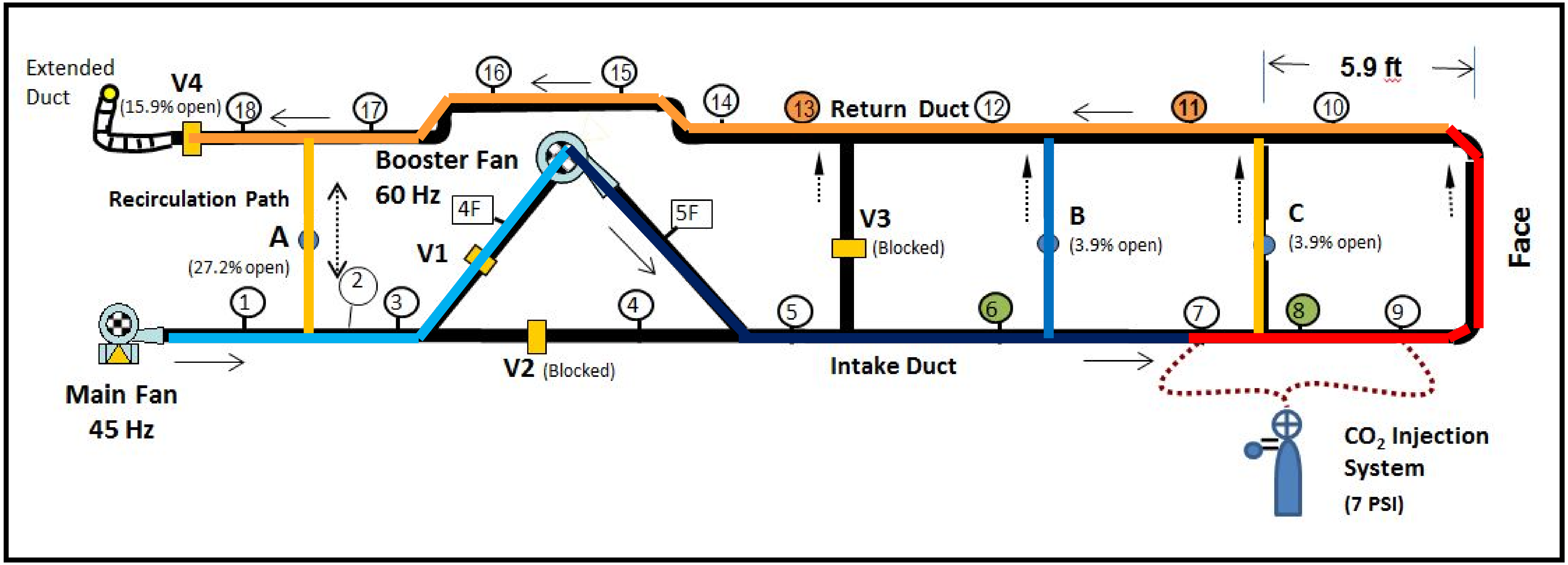


University of Utah Laboratory Model



Main Fan Only

University of Utah Laboratory Model



Main Fan + Booster Fan + Gas Injection

Experimental Conditions

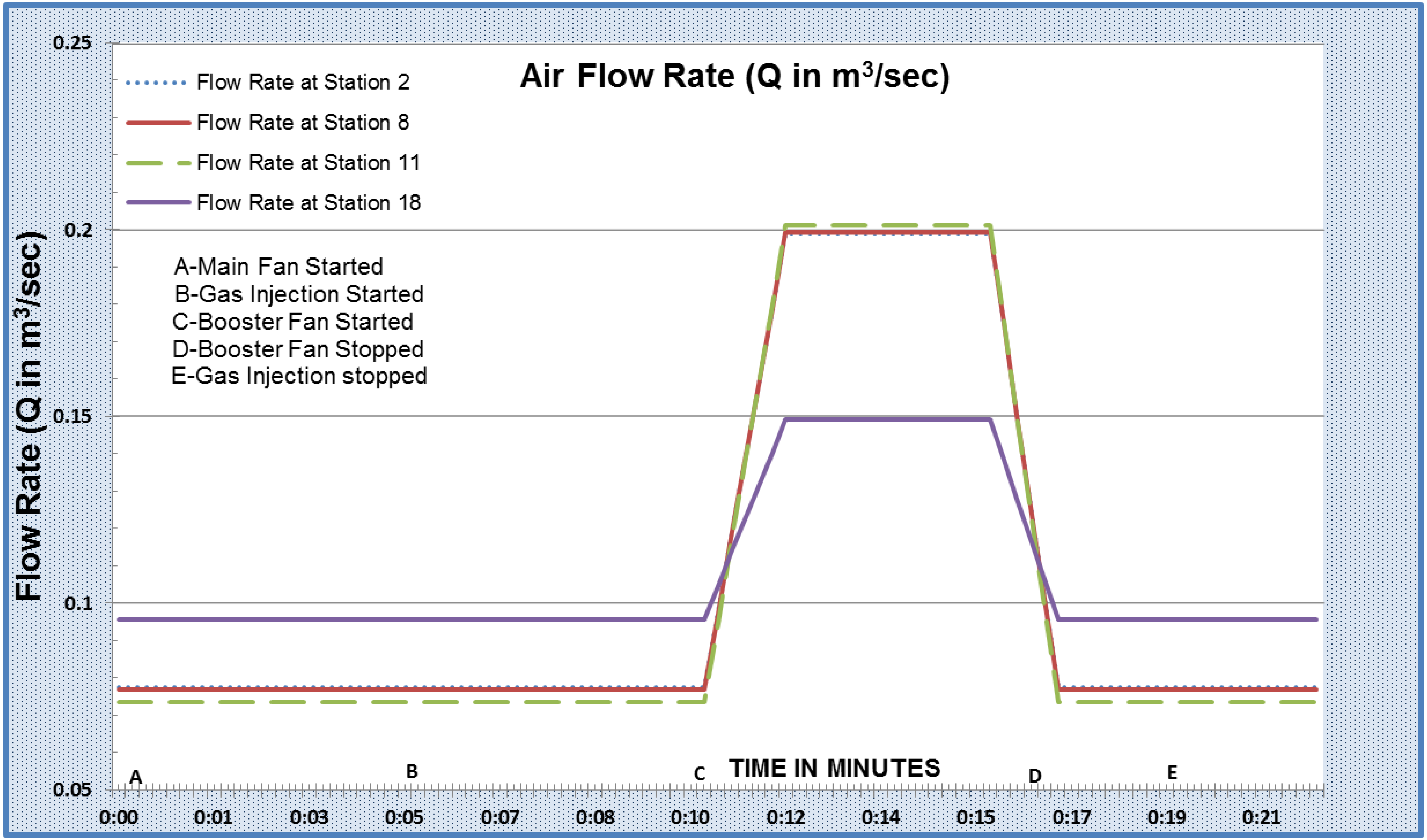
- The main fan was set to operate at low speed (45 Hz) and the booster fan at high speed (60 Hz)
- CO_2 gas was injected at station 7 and 9 at 7 psig
- CO_2 gas concentrations were monitored at stations 6 and 8 (intake side) and at stations 11 and 13 (return side)
- Crosscut A was 27.2 % open to induce recirculation
- Crosscuts B & C were 3.9 % open to simulate leakage in stoppings

Pressure-Quantity Results

Fan condition	Station	Hv	Velocity	Area	Quantity	Remarks
		pa	m/sec	m^2	m^3/sec	
Main fan only	2	10.9	4.62	0.016	0.077	**Leakage QL = 0.018 m3/sec**
	8	10.6	4.58	0.016	0.076	
	18	16.5	5.71	0.016	0.095	
Main and booster fan	2	72.2	11.91	0.016	0.199	**Recirculation 0.049 m3/sec**
	8	70.9	11.84	0.016	0.198	
	18	40.4	8.91	0.016	0.149	**RF = 0.25**

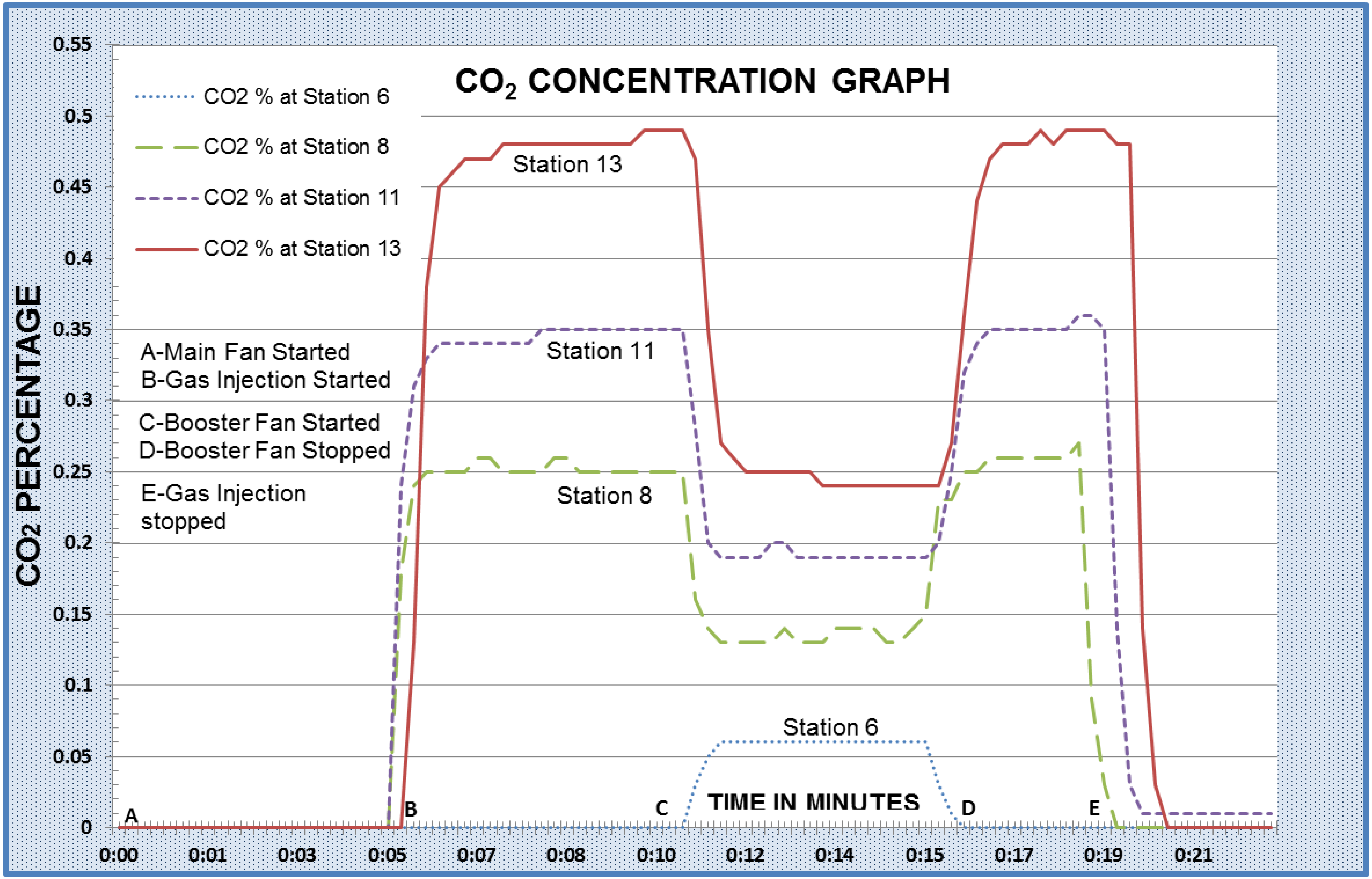
Pressure Quantity survey data of the Model

Air Flow Rate



Air Flow Rate vs. Time

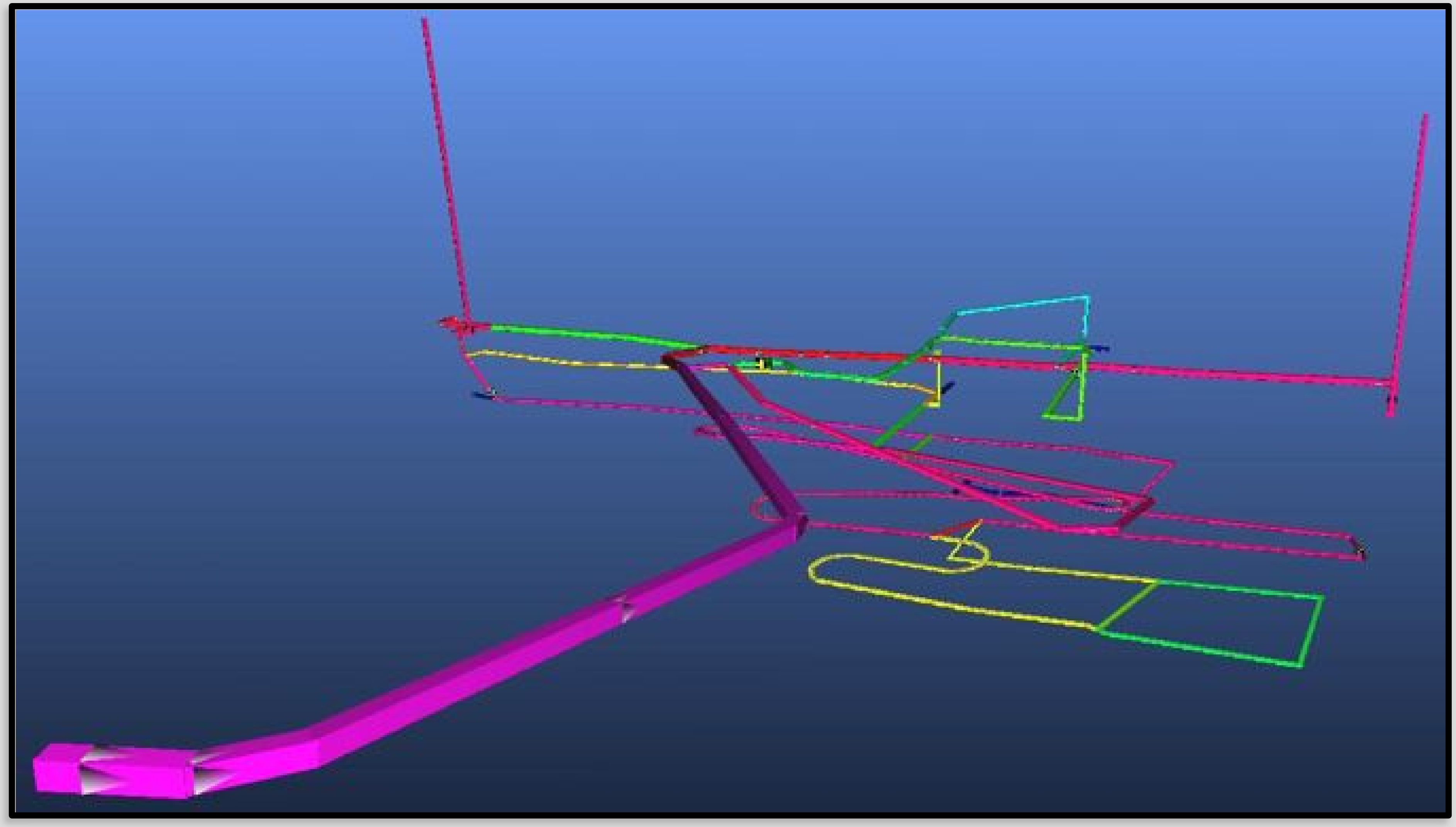
CO_2 Concentration Graph



Effect of Recirculation on CO_2 Concentration

Results of Laboratory Experiments

- Operation of the booster fan increases the capacity of the ventilation system, thus increasing the air velocity at the face
- For the same CO_2 injection rate, return air recirculation reduced gas concentration at the face by about 50%
- In a coal mine, an increased air velocity reduces the tendency of methane layering through better mixing
- Recirculation can be controlled by adequately sizing and positioning the fans



Numerical Simulations

Simulation using VentSim

- The application of laboratory model for research is somewhat limited.
- Numerical ventilation simulators play a critical role in ventilation research and planning.
- Simulators can be used to evaluate fan operating conditions, flow rates, and pressure losses in ventilation systems.
- A VentSim model has been developed to replicate the U of U Lab Model.
- VentSim is chosen over VnetPC because it includes an algorithm to detect recirculation.

Simulator Limitations

- VentSim has limitations for use of high resistances and small diameter ducts.

- Due to this reason, the numerical model of the laboratory model is scaled up by a factor of 5.

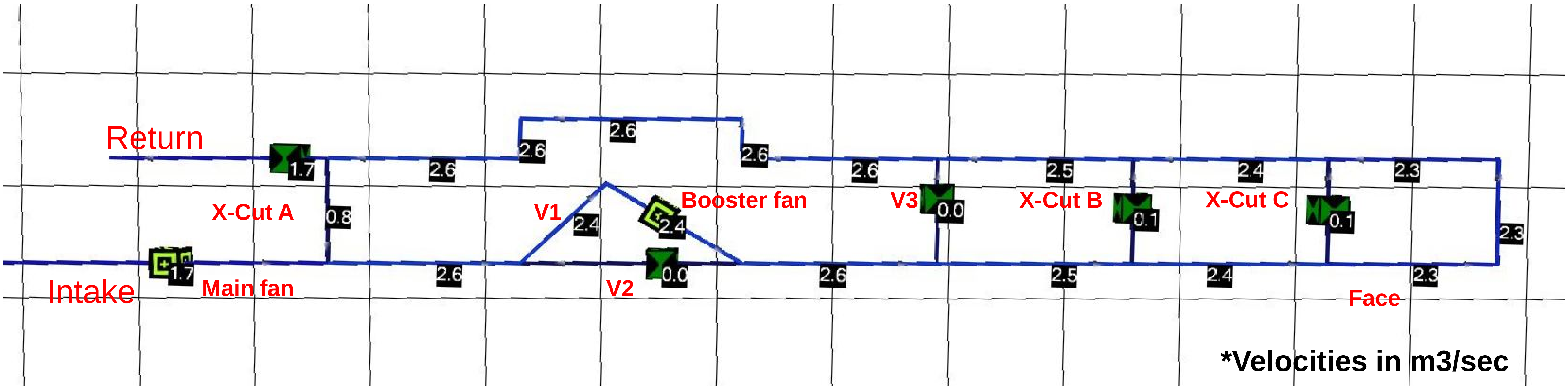
- To generate reliable results, the model is calibrated using data collected from Laboratory results.

- Two concepts are considered for calibrating the Numerical Model in VentSim:

✓ *Physical Similitude*

✓ *Dynamic Similitude*

Numerical Model of Lab Model



- The geometry of the model was constructed to resemble the physical model.

- The airway resistances were calculated using the scaled up duct dimensions and a friction factor of 30 E^{-10} lb min^2/ft^4.

- Regulators and stopping resistances were iterated to replicate the dynamic similarities with the laboratory experiment.

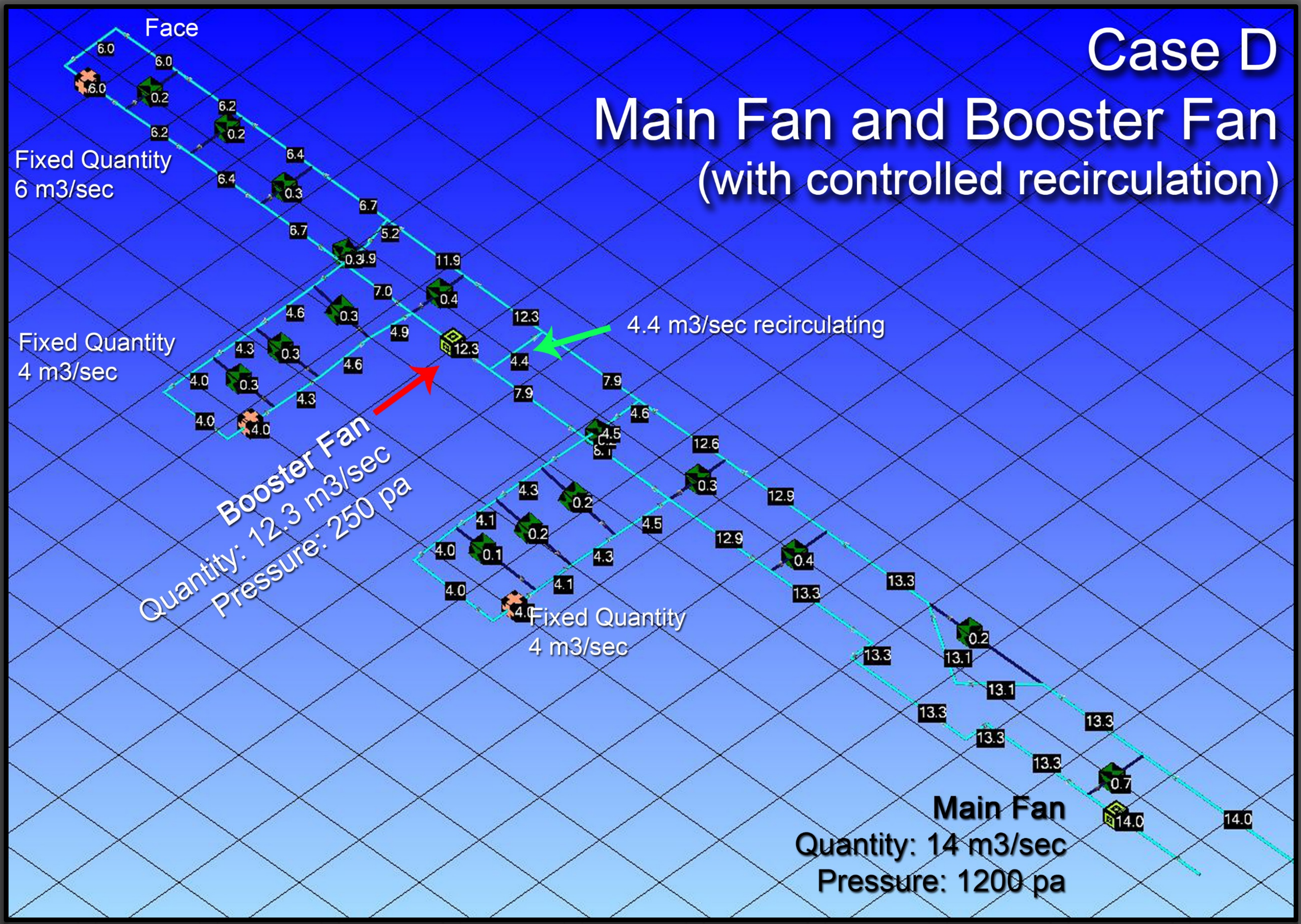
Experimental and VentSim modeling results

Description	Station	Experimental	VentSim
Diameter (m)	All	0.15	0.8
Main Intake Quantity (m3/sec)	1	0.15	0.8
Face Quantity (m3/sec)	8	0.2	1
Main Intake Velocity (m/sec)	1	8.9	1.7
Face velocity (m/sec)	8	11.9	2.3
Reynold's Number (main intake)	1	**91410**	**88516**
Reynold's Number (face)	8	**122130**	**116200**

Application

- The calibrated laboratory model can be extended to assess new designs of the mine ventilation system.
- Model is transformed into Exhaust system from Blowing system.
- The dynamics of recirculation are the same in both blowing and exhausting ventilation systems.
- It gives us more flexibility in testing recirculation, fan sizing and positioning in variety of mine designs.

Application



Results

Scenario	Main Fan			Booster Fan			Total Air Power (KW)
	Pressure (Pa)	Quantity (m^3/sec)	Air Power (KW)	Pressure (Pa)	Quantity (m^3/sec)	Air Power (KW)	
Case A Main Fan Only	3200	22	70.4	NA	NA	NA	**70.4**
Case B MF+BF at Site 1 with no recirculation	2000	20.1	40.2	800	19.7	15.8	**55.96**
Case C MF+BF Site 2 with no recirculation	2100	18.6	39.1	300	12.3	3.7	**42.75**
Case D MF+BF with recirculation	1200	14	16.8	250	12.3	3.1	**19.88**

Conclusions and Recommendations

Conclusions and Recommendations

- Recirculation can be controlled by adequately sizing and positioning the fan.
- Under current regulations, booster fan research in the U.S. is challenging, due to non-existent options for field studies.
- Computer Simulations, laboratory studies and comparison to Metal and Non-Metal mines are the only available tools for research.
- Modern Technology is now available like improved AMS, separate power circuits, wireless communication, etc.

Conclusions and Recommendations

- Research, experiences and regulations of other countries present important comparisons for the potential use of boosters in US.

- The use of booster fans can facilitate continued operation of a mine that is being considered for closure.

- Booster fan when installed with proper bulkheads, monitoring system, sizing and position; it works normally just like any other fan in mine.

- Detailed risk analysis is done before installation of the fan.

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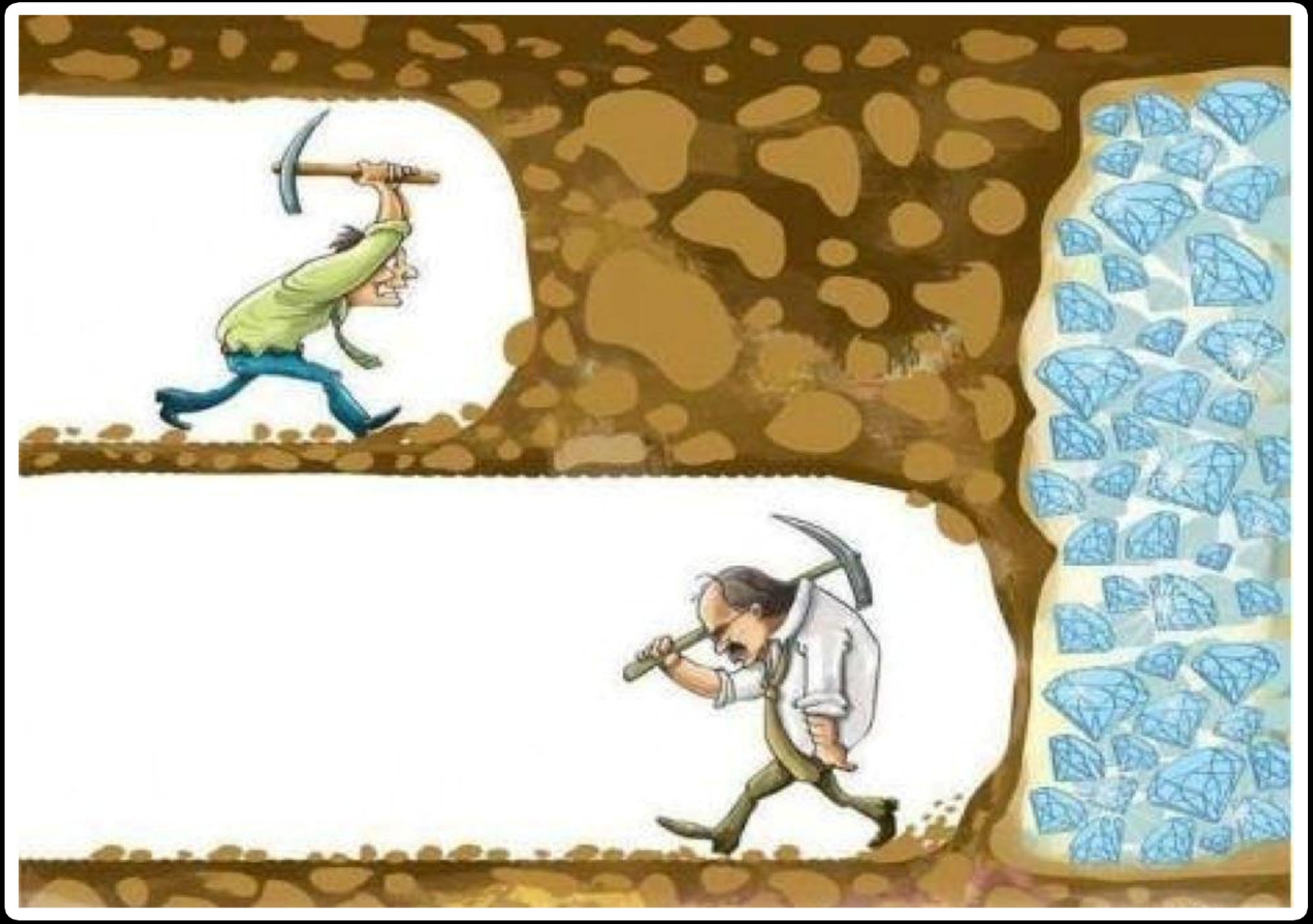

NEVER GIVE UP… KEEP MINING !!