Is your laboratory safe? Is your fume hood safe?...Let's IMPROVE the situation...

(in response to **Is your laboratory safe? Is you fume hood safe?** Appearing in **ENGINEERED SYSTEMS**, January, 2000, page 56)

The article, *"Is your laboratory safe? Is your fume hood safe?"*by Morris, Klumb, and Cirincione presented in the January issue of **ENGINEERED SYSTEMS** was thought provoking and well presented. For those of us who have been involved in laboratory systems and their designs, installation, testing, retrofit and maintenance, especially Laboratory Air Flow Control Systems (LAFCS), these revelations are not new. Performance defects associated with select LAFCS vendor system offerings[1] and their causes are not news. In response, this article attempts to add supplemental information that aids in setting the record straight and give a historical framework of how we have come to recognize some existing performance related problems and ways we've used our knowledge to design better technology. For instance, *snap shot* testing of only a hood or LAFCS does not give us the information we need about sustained LAFCS repeatable performance. The same occurs with regards to running the ASHRAE 110 "pass/fail" test on hoods. System performance six months after the tests are run are no longer meaningful. To know when performance is deteriorating is one of the important aspects, as well as having system indicators--when something goes awry--that provide information, warning a user. An especially disturbing example with most LAFCS vendor offering is "face velocity" information falsely displayed; no LAFCS measures face velocity and use this to control hood exhaust; this is not possible with current technology. An example: most LAFCS vendor performance indicator offering is "face velocity." When the information is displayed, it leads a user to falsely assume he is protected when he is not.

There are now safer systems available. These systems will improve containment ventilation in the laboratory work place and increase safety with reliable performance indicators. By looking to back on history's failures and successes, we've been able to devise a proven LAFCS complete with an Automated Sash Positioning System (ASPS) that is extremely successful in new designs. Cost effective retrofit is available for jobs using constant volume and for jobs where unacceptable LAFCS systems have been installed. These designs have been proven by use of the ASHRAE 110, and other tests, and in order to ensure installed systems are achieving the desired and designed containment, we believe that the systems should continue to be challenged.

The bad news, as stated in the article, is that despite improved technology on the market, many of today's labs are still not up to standard. The worker appears to be the only one paying the price--most often five, ten or fifteen years after exposure begins. To many owners, architects, contractors and some engineers, a fume hood and exhaust fan is a detail on a drawing that solves a problem concerning code or user request. Too often they view laboratory ventilation design, especially with regard to fume hoods and the exhaust systems that serve them, as a "plug in". They use a variety of parts to assemble similar systems, hoping for similar results. In fact, this process requires and deserves a great deal of thought to assure that we avoid the potential for health and safety concerns, *even on the part of the user*.

It is most interesting to note that the focus on the problem in the workplace was and still remains ventilation--It is not simply a specific aspect or item of equipment such as hoods, supply diffusers, their locations in a room, room temperature and humidity, or other such factors. What changes have transpired over the past five decades? How have these changes improved this containment ventilation goal? Today, 100 years after the first attempts to purge pungent smells from a laboratory, it is time to objectively re-examine the evolution of the laboratory airflow ventilation containment process. This examination will help us understand what undesirable features or concepts got us to where we are today.

THE FIRST CONSTANT FACE VELOCITY FUME HOODS

The fundamental reason we need to utilize constant fume hood face velocity control action is containment ventilation safety, not energy saving. This goal--and different schemes for achieving this goal--is not new. The first successful attempt to control hood exhaust flow as a function of hood sash position was in the 1940s. During the atomic energy era, Weber developed and installed a mechanical mechanism for varying hood exhaust flow with sash position. One of his stated goals was "constant fume hood face velocity with sash position". (To learn more about Weber's idea disclosure, visit **www.TAAI-svc.com/engineer/html/AECD**.) The invention disclosure illustrates how Weber accomplished the containment ventilation goal.)

Weber's invention utilized a direct linkage mechanism with a cam profile, narrowing the flow through a conventional single-bladed butterfly damper installed in the exhaust ductwork. He was successful in producing a constant hood face velocity at all sash positions. With the rack and pinion damper drive/linkage arrangement shown, Weber also included a locking device to allow the sash to be closed allowing exhaust volume to increase when an emergency arose within the hood. Recently, both the use of constant face velocity and the use of the purge concept have returned as design features of a safer laboratory ventilation system.

The early AEC labs in which Weber worked did not have air conditioning. The ventilation system was "draw-through" only. The scientists working in these labs were concerned only with containing life-threatening materials in the hood so they did not breathe it or become exposed to it. By utilizing a "draw through" variable air volume hood exhaust flow scheme, room supply was automatically varied with the exhaust. The supply airflow was exhaust flow induced in response to the hood exhaust flow rate. Both were dependent upon hood sash position.

It is interesting to note that these AEC labs, where experiments were being done with the "really bad stuff," were located in Los Alamos, NM at an elevation of 7410'. The anticipated low temperature for a summer day was 57° F. This implies that comfort conditioning of the air entering a lab building was not needed except late in the afternoon of a summer day.

The AEC typical laboratory in the early 1940s consisted of a single-story building with construction configuration illustrated in Figure 1.

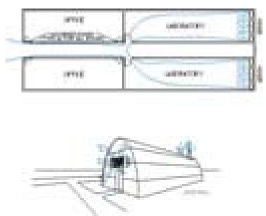

Figure 1 - Early AEC Laboratory Building Arrangemen

The laboratory building had a central personnel/service corridor along its major axis with laboratories off both sides of the corridors, as shown. Fume hoods were most likely installed along the exterior walls of each laboratory module. A single dedicated, roof-mounted, belt-driven exhaust fan powered the hood exhaust. With this configuration, make up air for the hood was drawn from the outside of the building, through a unit heater mounted above one of the hallway exterior doors, down the hallway, through a louver in the laboratory door. The resistance to airflow into the lab was only slightly greater with the door closed than with it open.

Several subtle but significant lessons can be learned from these AEC laboratories:

First, if hood containment was not being achieved, a Geiger counter placed to a user's chest would quickly indicate failure of the hood and failure of the airflow system to contain materials in the hood. Containment testing was the norm.

Second, it was recognized that if the face velocities became too high or were not right, "turbulence or other air action sufficient to cause eddy currents, back drafts, etc. of such a nature as to provoke any danger from toxic or radioactive materials as regards to the operator" would occur. Too high a face velocity, or too low a face velocity, was obviously known to be a bad trait.

Third, the safest way to use the hood was recognized to be with the hood sash closed. The appropriate emergency response by the operator to an unplanned event was to close the hood.

Fourth, as air entered the room through the door, it swept the room and all materials liberated or generated in the room toward the hood. Disruptive eddy currents were absent. The air entering the hood was drawn into the hood in a somewhat uniform (iso-kinetic) flow.

Finally, once Weber's system was applied to a fume hood, users could make incremental changes to hood design and assess the effect on the hood's containment capability. These changes included addition of a safety shelf and airfoil on the bottom of the hood and the replacement of square posts with more aerodynamic entrance sections.

With the hood exhaust flow rate varying with the sash opening operating in rooms without forced supply air features, substantial containment enhancement was realized in the design of the basic single vertical rising sash hood. This work impacted the design, so that even today no reference to occupant comfort exists in the codes or standards regarding laboratory ventilation.

THE BY-PASS HOOD AND CONVERSION TO DILUTION VENTILATION LAFCS

In the 1950s, we started utilizing air conditioning in laboratories and went to "push-pull" LAFCS concept. Lacking the technology to accomplish supply/exhaust flow tracking, designers shifted to a constant volume system using a bypass type hood. However, forcing air into the laboratory created a new and different set of problems. To overcome the problems, designers began doing things that they thought would help. A significant but subtle change in LAFCS concept resulted. Designers began to change from variable air volume, constant face velocity hood exhaust flow, with a goal of containment within the hood, to constant fume hood exhaust flow using hoods with bypass sections. With this latter scheme, when it was determined that bypass hoods did not contain as well as the vertical rising sash type hood employing the Weber hood exhaust flow concept, a transition from a containment ventilation to dilution ventilation took place with increased air changes per hour in the laboratories for dilution purposes.

Poor performance of a conventional bypass hood can be explained by understanding how the bypass mechanism works. Conceptually, as the sash rises from a closed position, the hood face opening increases. The top of the sash blocks the bypass opening, thus ensuring, from a theoretical standpoint, that the size of the opening into the interior of the hood is always the same. The resistance of flow into the hood, through the bypass section of the sash opening is assumed to be the same. This assumption is false. The flow through the bypass goes through a grill, adding resistance to the flow. A typical bypass section is less than 18 inches high and the width of the hood. The sash can typically travel up to 24-30 inches. Therefore, as the sash opens to a point that it completely blocks off the bypass the face velocity remains relatively unchanged. As the sash rises further, the face velocity begins to fall. The face velocity through the hood sash opening is not constant at various sash positions, and can vary by as much as 300%. This factor often precipitates outflow from the hood into the breathing zone when the velocity through the opening exceeds about 150 fpm.

FACE VELOCITY MEASUREMENTS

Authors Morris, Klumb, and Cirincione suggest that "average face velocity measurements" are not a good criteria for judging the performance of a fume hood. In many instances this is correct. However, a blanket condemnation of this method is not completely justified. Granted, face velocity measurements taken with a hotwire anemometer when the indicating needle is swinging wildly and the device user "visually" averages the indications may not be the best data, but it is not necessarily meaningless. It is important to consider the accuracy and precision of the instrument, where and how the signal is read, and the usefulness of the information it provides. However even with its faults, sometimes even poor face velocity data taken with a hotwire anemometer can at provide guidance to a knowledgeable safety professional concerning hood performance. Figure 2 illustrates such a situation. The problem in this particular situation is not what the readings indicate, but rather the lack of meaningful activity by those responsible to address and correct the ventilation containment problem identified. The same concerns associated with accuracy and precision hold true for rotating vane anemometers.

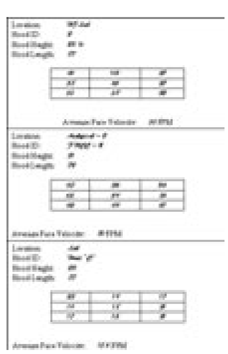

Figure 2 - An Example Of Face Three Velocity Measurements indicating Poor Fume Hood Containment Performance (Chemical Plant, Upper Gulf Coast)

To illustrate the utility of face velocity measurements in a fume hood, consider the array of individual pitot-static tubes is installed in a fume hood face as is illustrated in Photo 2. With this arrangement the velocity pressure signals from these tubes are sequentially multiplexed and sampled with the same high-quality differential pressure transducer with air velocities calculated to produce significant measurement results. These results can be displayed and recorded with a computer, as is illustrated in Photo 3, and be used to benefit fume hood containment ventilation and especially problem identification and correction.

Photo 2 - Pitot-static Tube Array for Fume Hood Face Velocity Sampling

Photo 3 - Computer Driven Pitot-Static Fume Hood Face Velocity Sampling Scheme

Figure 3 - Typical Computer Output Record for Pitot-Static Fume Hood Face Velocity Sampling Scheme

In this situation, the average velocity sensed at each of sixteen probes was multiplexed back to and conditioned via computer. Associated with the velocity measurement at each point is the standard deviation of the 100 velocity pressure samples taken at that point. The standard deviations reflect the turbulence of the air in the vicinity of the probe. This information can be used to identify and isolate disturbance factors. Trace gas performance testing cannot yield information such as this, but provides only "pass-fail" information. No assistance in isolating problems with the LAFCS is revealed. However, there is good correlation between the results provided by the trace gas performance method (ASHRAE 110 Test procedure) and the average mean face velocity measurements in fume hood set up and test situations.

A significant problem exists today with the use of face velocity and LAFCS. Although commonly incorporated into system design, no LAFCS supplier can sense face velocity in an operating hood with currently available technology. If the average velocity cannot be sensed in an operating fume hood, how can fume hood face velocity be controlled? It is for this reason NFPA 45 dictates that hood flow, which is measurable, be indicated as a means of indicating hood performance. What LAFCS suppliers sense and what they control with their products is illustrated and discussed in "*Changes to National Fire Protection Codes for May 2000*"at **www.SAAI-svc.com/engineer/html/NFPA45.htm**. Safety and containment ventilation implied by some LAFCS suppliers lead the user to assume he is protected while in fact the hood face velocity reading may be false.

Using the above approach, we have tested numerous hoods with both constant volume-bypass systems and a wide variety of VAV control devices. Our results indicate that constant face velocity is not maintained when the sash position is adjusted. Our results dispute the claims made by numerous LAFCS suppliers that their devices accomplish the required linear control functional relationship.

IMPROVEMENT TO THE PERFORMANCE OF FUME HOODS

Our firm has begun, through experimentation and literature review, to isolate and qualify factors negatively impacting containment ventilation with fume hoods. From a safety standpoint, we are also trying to validate why containment ventilation is better than dilution ventilation. Our efforts have followed and benefited from the Weber type approach. We employ product we have helped develop and tested extensively, Accu*Aire Controls, **(see http://www.accuaire.com)** to provide precise, accurate and repeatable hood versus sash position flow controls. The effort has been aided by the New-Tech's Automatic Sash Positioning System (ASPS) **(see http://www.accuaire.com/schemes/asps.htm)** to ensure repeatable air flow and sash position speeds of response.

With fume hoods, some of the factors and the differences are obvious and some are very subtle and compounding. Clearly hood performance depends on the type of hood and its use in constant volume or variable volume application. Our research has shown that rounded hood inlet sections are an improvement over 45° tapered inlet sections, which are an improvement over square inlet sections. We also found that hoods with greater than the nominal 32" depth, yields better containment performance with increasing depth, regardless of type. Likewise, the deeper the emission source is placed in the hood, the greater the containment[2] It has been demonstrated that the ideal fume hood would consist of a low velocity wind tunnel about 8' wide, 8' high and about 32' long, with a back constructed of perforated metal plate. Unfortunately, limited laboratory space does not permit this wind tunnel approach.

Many of the factors we examined have been previously identified and published, stemming from the work of the atomic energy era. (See the proceeding, ***LABORATORY DESIGN FOR HANDLING RADIOACTIVE MATERIALS****,* Building Research Advisory Board Conference Report No. 3, National Research Council, National Academy of Science, November 27 and 28, 1951, published May 1952, especially pages 26-27, 37-38, and 46-48.) Note that the true goal of VAV controls in laboratories is to aid containment of fugitive emissions in a hood. It had nothing to do with energy savings, which turns out to be a secondary benefit in a well-designed and performing laboratory air flow control concept, especially if Accu*Aire LAFCS and the New-Tech ASPS control features are combined in the same LAFCS application. The fundamentals of curved inlet sections, a sash cap, a safety shelf, a vertical rising sash, and other such elements especially with an ASPS feature control coupled to a LAFCS that includes repeatable control of hood exhaust flow at all sash positions cannot be beat regarding containment ventilation. We have also confirmed that horizontal and combination sashes don't aid in hood containment.

The results of research recently done by Steve Lacey at Texas A&M University indicate that a significant increase in containment can be achieved through hood enhancement. The following are included improvements: curved air foiled entrance sections including along and under the bottom of the sash; replacement of the conventional baffling system with a full back perforated baffle system; a full width sash cap; a full-width back slotted exhaust pick up for hood exhaust and a safety shelf that has been rounded on the leading edge as it sits below the air foil. With these hood enhancements completed, testing with a prototype hood has produced no measurable fugitive emissions from the hoods using the ASHRAE 110 tests.[3]

OTHER RECENT NOTABLE ATTEMPTS TO IMPROVE TO THE PERFORMANCE OF FUME HOODS

The last few years have seen two notable but misguided attempts to impact the performance of fume hoods with some special gimmicks. These are the "vortex hood" and the HOPEC. Hood. With the "vortex hood", an attempt has been made to control fume hood face velocity by use of a complex vortex sensing system and upper baffle mechanism that changes the position of the 45-degree upper baffle, as illustrated in Figure 4 [4]. This control scheme depends upon the existence and detection of a vortex that is formed by the air that circulates in the upper cavity of the hood. Theoretically, a vortex is caused to form by the flow reversal of air changing direction in the hood and exits the hood above this upper top baffle. A sensor detects the strength of the vortex that sometimes forms and adjusts the upper 45° baffle accordingly. Unfortunately as the sash closes, a throttling valve, and the vortex reduce flow through the hood, if it exist, decays.

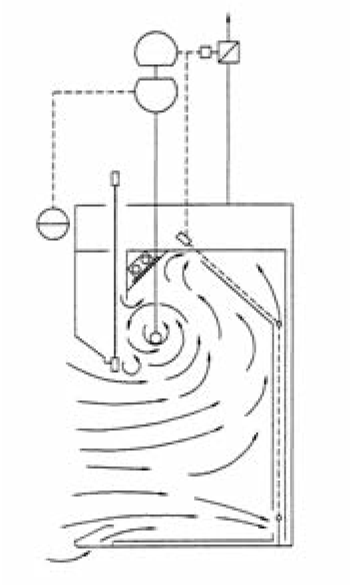

Figure 4 - Patent Concept Drawing of the Vortex Fume Hood Control Scheme

Figure 5 illustrates how the vortex, if it exists, decays in a vertical rising sash hood with sash opening and reduced flow. Measuring the strength of the vortex in the top of the fume hood as is decays, and especially attempting to use this signal as a control sensing means, is foolishness. The Lacey hood, illustrated in Figure 6 with perforated back baffles and other enhancements, eliminates factors that would give rise to the formation of a vortex in the top of the hood. In additions, uniformity of hood face velocity across the hood sash openings, at any opening, is much improved when the back baffle is replaced with a perforated plate and other enhancement explored with the Lacey hood.

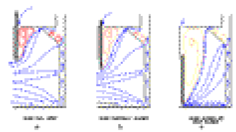

Figure 5 - Vortex Decay in Vertical Rising Sash Fume Hood

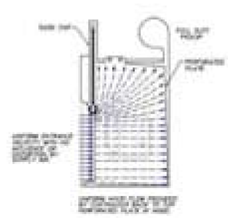

Figure 6 - "Lacey Hood" with Perforated Baffle and Other Enhancements

Combination sashes, horizontal sliding sashes, vortex dampers, and all sorts of things have been tried in our quest to improve hood containment. Generally these developments benefited someone financially and were accompanied and promoted with substantial marketing hype. Most often little if any improvement resulted. An example of this is the Hand Operated Positive Energy Control (HOPEC) sash system employed in a fume hood.[5].

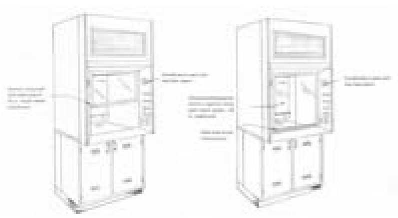

Figure 7 - HOPEC Fumehood Illustrated in Vertical Rising and Horizontal Sliding Sash Configurations

The HOPEC concept is that since a sash is rarely fully open, it makes no sense to establish a total exhaust requirement for the fully open sash position. The hood is converted to a bypass type vertical rising or horizontal sliding sash (with one panel always open) face configuration. Sash locks are installed to require the operator to deliberately open the hood beyond the half height position. The hood exhaust and room supply flows are manual balanced to achieve a constant volume flow balance. This concept, save perhaps for the sash locks, is not new and was published in the late 1940s and early 1950s per the bypass hoods earlier discussed. The HOPEC concept compounds and worsen the bypass containment performance problem by ignoring what happens when hood exhaust and room supply flow balance gets out of synchronization and is heightened when a user neglects to consider the effects caused by low face velocity when the sash position is greater than half height.

AIR CHANGES PER HOUR AND LABORAOTORY AIR REPLACEMENT

Authors Morris, Klumb, and Cirincione correctly state, "Most laboratory workers are unfamiliar with the internal workings of their ventilation systems. Almost all laboratories use 'once through air systems' with 100% outside air make up systems." However, the authors incorrectly state, "On the average, all of the laboratory air is replaced with fresh outside air ever 6 min. At this rate, laboratories should smell almost as fresh as the outdoors." The air in a laboratory is not purged and replaced in a laboratory with each air change, unless the laboratory is constructed to be a wind tunnel, a situation similar to the early Weber laboratory/hood LAFCS. This speaks to the very heart of the problems with dilution ventilation versus containment ventilation.

Dilution dictates a required number of air changes in a laboratory in an order to keep fugitive emission concentration down. Fugitive emissions are emissions generated in and escaping a hood or emissions resulting from procedures done on a bench that should have been done within a hood. Hood or room exhaust airflow and room supply make up airflow must be maintained regardless of hood exhaust flow control, VAV or constant volume.

Our office has a full scale, four-fume hood working model mock, which we and graduate ES&H students at Texas A&M University experiment in. This facility is well instrumented for precise and accurate air and velocity measurements as well as the instrumentation needed for the ASHRAE 110 test (Miran 1A). Some time ago, we set out to validate our logic concerning Air Changes per Hour (ACH) and fugitive emission concentration in the laboratory workspace. By releasing SF_6 into our test room at varying rates, in varying locations, and with varying and constant hood and room exhaust flow rates, we learned the following:

> Regardless of the number of ACH, if the SF_6release rate was constant, the concentration of SF_6 appeared to build up to some terminal value. The rate of build up depended on: (a) the liberation rate of SF_6 (8,6,4 lpm), (b) the location of the emitter in the room, (c) the location of make up air delivered into the room (all being exhausted through on or more of four fume hoods in the room); and (d) the dilution rate (SF_6 release rate/ACH).
>
> The terminal SF_6 concentration value was fairly constant for a given liberation rate and dilution rate. Concentration differed in the room depending on whether the measurements were taken in dead spots or directly in the stream between the supply air and the fume hood faces. The room was not purged with each air exchange.
>
> If a fixed volume of SF_6 was released at one time (gas injected into a balloon and the balloon punctured) and the ACH was held constant, the room concentration decayed with time and the time was different in some similar situations. The concentration did decay steadily after release of the emitter gas ceased. The time required for total flushing differed in each case, even when the liberation and ACH rate remained constant, some times as long as 12 to 24 hours.

The lessons learned from this experiment were:

> ACH does not guarantee user protection from fugitive emissions released from the hood or liberated in the room. To protect the users, contain the material in the fume hood, and when material is released in the room, vacate the room until a substantial time has passed and dilution ventilation in the room has purged the room of fugitive emissions. This assumes that the room remains pressure negative to the adjacent areas per NFPA 45.
>
> 100% containment is possible without fugitive emissions getting into the workspace where

work is conducted in a properly designed and installed fume hood with ventilation containment control achieved with a properly operating LAFCS.

CONCLUSION

We realize that as long as people are involved, laboratories will never be 100% safe. For example, there are no engineering solutions that can protect a laboratory user from self-folly such as conducting experiments on a bench that should be conducted within a fume hood. However, with advancing and improving technology, significant engineered system improvements have been made which can be incorporated into existing and new laboratories to significantly minimize risk, while at the same time, significantly enhancing performance and reducing operating cost. Further, we can use engineering solutions to maximize containment control regardless of the material used within a fume hood. On this basis we seek, through engineered solutions, a reduction in risk to laboratory users associated with fires, acute or chronic carcinogenic, radioactive, or biological materials exposures; and costs associated with damages including repairs and clean-up. If any laboratory air flow control and ventilation system is to create a safe working environment subject to "fail safe" considerations across all possible scenarios, the following conditions, ranked by order of importance, must be met:

> First, maximum containment of materials in the fume hood under all operating conditions.
>
> Second, maximum containment of materials in the room that houses the fume hood under all operating conditions.
>
> Finally, if possible, provide comfort conditions for users working in the rooms that house the hoods. This however is not a code requirement.

Containment ventilation safety is our primary goal, and if energy savings result because of containment ventilation safety improvements, all the better. Finally, although we have come a long way toward greater safety in the laboratory, there is still much to be done. As pointed out by Morris, Klumb and Cirincione, many laboratory workers are still suffering unnecessary exposure to health-threatening chemicals. Luckily, the technology exists to significantly change this problem. We, at Accu*Aire have taken a careful look at what works and what doesn't and have designed our products accordingly. If you have an interest in laboratory airflow control systems, containment ventilation, and features, function and benefits, and would like to know more, visit our websites at **www.SAAI-svc.com/engineer/html/tech-notes.htm** and **www.accuaire.com/html/articles.htm.**

Review some of the technical information and findings generated both "in-house" as well as those findings reported by other engineering researchers.

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1. see **FACTORS THAT WORK TO DEFEAT THE USE OF THE "THROUGH THE WALL" VELOCITY CONTROL CONCEPT IN FUME HOOD EXHAUST WITH SASH POSITION CONTROL** (**www.saai-svc.com/engineer/html/throughthewall.htm**) and **FACTORS THAT WORK TO DEFEAT THE APPLICATION OF THE "SPRING AND CONE" TYPE VALVES IN LABORATORY AND OTHER PRECISION AIRFLOW SYSTEMS** (**www.saai-svc.com/engineer/html/springandcone.htm**).

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2. Fuller, F. H., and Etchells, A. W., The Rating of Laboratory Hood Performance, ASHRAE Journal, October 1979 page 49.

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3. Steven Edward Lacey, "Design and Evaluation of a Prototype Laboratory Emission Control Device for Use in a Variable Volume, Fume Hood Face Velocity Reducing System", unpublished Master's Thesis, Dr. James C. Rock, Thesis Advisor, Department of Nuclear Engineering, Texas A&M University, College Station,

Texas, August 22, 1999

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4. U.S. Patent No. 5,697,838, *Apparatus and Method to Optimize Fume Containment by a Hood*, Inventor: Robert H. Morris, Wharton, N.J.; Assignee: Flow Safe, Inc. Denville, N.J.; date of issue: December 16, 1997.

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5. Jerrold Koenigsberg, "The laboratory fumehood: Efficiency and energy conservation", The American Laboratory, October, 1984: This arrangement is illustrated in Figure 7

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