

# CICIND

**REPORT**

**CICIND MAGAZINE**



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**94<sup>th</sup> Conference/Online  
Rotterdam  
20<sup>th</sup> - 21<sup>th</sup> May 2021**

# **CICIND**

**INTERNATIONAL COMMITTEE FOR INDUSTRIAL CONSTRUCTION**

# CICIND REPORT

Vol. 94

July 2021

Editorial Board: Hermann Hoffmeister (Editor), Gary Eastman

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## Words from the President June 2021



*Albert de Kreij*

Now that CICIND has conducted its second “Virtual Conference” we can proudly say that our association has had the ability to adapt to the difficult demands of the Corona pandemic.

Clearly, the pandemic has been a global tragedy and its effects will be felt in many ways for a long time to come. During the pandemic,

like many other organizations, CICIND has developed the skill of conducting a conference remotely, allowing attendees to join through the internet. This skill will remain important even after, hopefully soon, the pandemic has vanished completely. Clearly, CICIND wants to go back to in-person meetings and the first of these will hopefully be the Autumn 2021 meeting in Dresden, Germany. We have decided however, that future in-person meetings will be made accessible remotely, granting access to those who are interested in the knowlegde of our members, but who are unable to justify the time and expense of attending in person.

The ability of CICIND and its members to adapt to changing circumstances was manifested very clearly during our 20 and 21 May 2021 conference. We have known for some time now that CICIND members have knowledge and skills related to many things other than chimneys. In recent meetings, we have seen papers on ductwork, cooling towers and solar towers. In the 20 and 21 May meeting, we have also seen how virtual reality can be applied to industrial inspections and how CFD calculations can be used to predict the warming up and the emissions from chimneys. These types of new developments will keep CICIND relevant and attractive in times of great change.

Contributions from members will always be the primary mechanism for CICIND to present itself to the professional world. Additionally, CICIND does of course finance studies of its own. In selecting future studies, CICIND will be looking for topics that are innovative and that could grab the attention of significant groups of people. If successful, this approach will make the CICIND meetings interesting for a larger audience, increasing both the in-person as well as the virtual attendance to the meetings.

With the added option of virtual attendance and with a strong innovative push from both the CICIND membership and CICIND itself, we can be confident that CICIND will thrive for many years to come.

*Albert de Kreij*

## Editorial

Early in June, my wife and I had a nice glass of chilled white wine in a garden restaurant by a lake near my home in Germany. This was the first visit to a restaurant in a long time. Many countries around the world seem to be returning to normal soon, although the coronavirus remains, and different variants are popping up. Vaccinating the world's population will help overcome the virus attack. The underserved countries of the world desperately need the not altruistic help of the rich countries providing vaccines to reduce virus effectiveness. The goal is to get back to normal life.

The discussion at the end of our second virtual CICIND meeting hosted by Hadek, Rotterdam, on May 20 and 21, 2021, showed that many of the CICIND companies have suffered from ongoing difficulties. On the other hand, we have recognized a further stage in the digital transformation process. You will find that digital communication in companies represented by our members has reached a higher level. Quick ZOOM or TEAMS chats are more common, working documents can be visually shared more quickly and discussions can be made from home. There is less need for expensive and time-consuming flights and car journeys during a work process. The working process is much quicker and easier than before, more focused on the essentials.

Even so, personal meetings are just as important as they were before. A first meeting with an unknown person or company, difficult negotiations with an open outcome etc. are still necessary as ever. I cannot imagine that an organization like CICIND could survive and be worth being part of without face-to-face meetings.

This year's autumn CICIND meeting in Dresden will be the next opportunity for all CICIND members and guests to come together, listen to the lectures and meet friends and colleagues. We will try to organize a video system so that members who cannot travel can follow the lectures from home. The announcements for the next CICIND meetings can be found in this report. You will receive the appropriate invitation to the Dresden meeting on October 20 to 23, 2021 in good time.

We are currently working on a new webpage for CICIND. It is not only to refresh the layout and presentation of our webpage, but we want to simplify the handling of this webpage with modern tools. We want to highlight information about companies represented in our

international organization. We intend to offer a business page for every company with their presentation. Because we are still working for this new webpage, we are open for new ideas.

Our CICIND data bank system has been continuously improved and is now at a good standard: the CICIND secretary may carry out membership administration in a much simpler but more

detailed manner; members can view their own data on the website and send corrections; the handling of conferences with registration and resulting lists have been improved; all presentations with the speakers are saved and can be easily opened. CICIND accounting can look back on two years of experience with balance sheets, profit and loss accounts and detailed lists to carry out the annual audit. Our next challenge is to try to have proper documentation of all procedures.

We welcome 5 new CICIND members in the first half of 2021, but we have to intensify our efforts to attract further new members. You are all called on to address new members and to help increase the diversity of technical input and experience. We look forward to adding the local universities in the conference cities to the conference program. Technical innovation is possible with the use of many resources. CICIND conferences should be a platform for innovation.

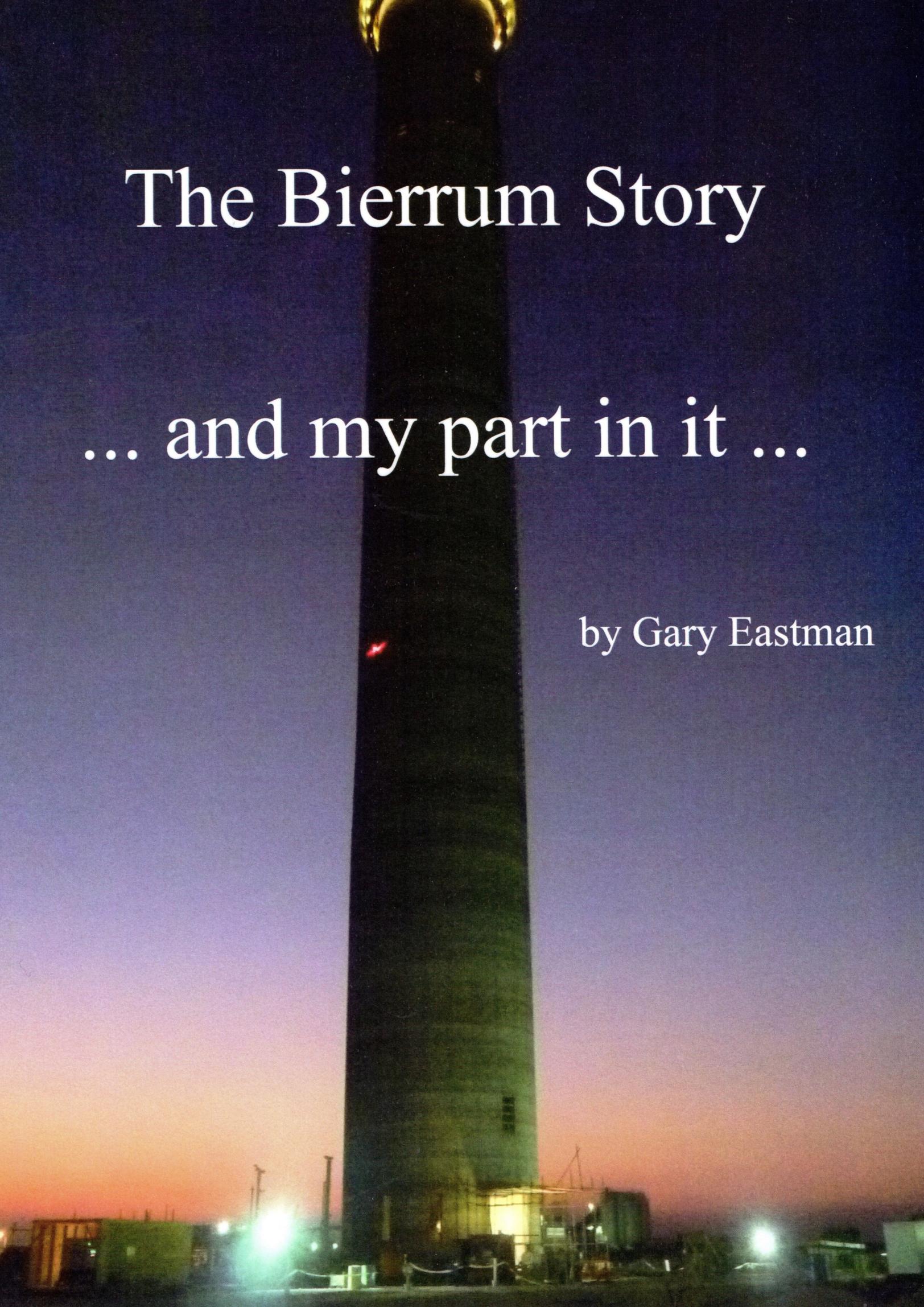
I was very pleased to see such technical innovations at our 94<sup>th</sup> Virtual CICIND Conference with augmented reality to improve inspection procedures being a tool for the benefit of inspectors and clients. There were also papers about advances in the liner technology, recommendations for Gas Turbine stacks and the impact of power plant startups. In addition, we gave a final report about the CICIND supported Research & Development and many other new ideas in our business area. You can find all of these lectures in this CICIND Report.

I am looking forward seeing you in Dresden!



*Hermann Hoffmeister*  
*Secretary of CICIND*

*Hermann Hoffmeister*



# The Bierrum Story

... and my part in it ...

by Gary Eastman

## Chapter 13 – The International Chimney Committee –



Membership of CICIND played an enormous part in our recovery and at the same time became an essential marketing and networking tool in the international marketplace. Bierrum and Partners had essentially been a UK based company with the occasional contract outside our borders whereas Bierrum International's overseas turnover was about 60% of the gross. We needed to broaden our horizons and get ourselves known outside the UK and there was no better place to achieve that aim than by using the networking facilities available within CICIND.

CICIND (“Comité International des Cheminées Industrielles”) was formed in 1973 in Paris, under the Presidency of Marius Diver of France. The need for such a body had been demonstrated at the first International Chimney Symposium, held in Edinburgh earlier that year. This symposium highlighted the contradictory requirements of the various National Codes governing the design of industrial chimneys as well as the lack of knowledge about the processes leading to accelerated deterioration of chimneys at that time.

Originally CICIND comprised a small informal group of engineers who shared an interest in industrial chimneys. Membership was by invitation. In 1981, under the Presidency of Dr Hermann Bottenbruch of Germany, the organisation was formalised as an Association and expanded to be open to anyone working in industrial chimneys, an annual subscription being charged.

By 1986, the membership had grown to 86, representing chimney owners, builders, component suppliers, consultants and academics from 20 countries worldwide. Statutes were agreed and the Association was registered in Zurich, Switzerland. Its annual membership budget had grown to 6,500 Swiss Francs which paid for a secretariat, research and publications. Since then the membership has continued to grow, passing the 240 mark in 2017. It is now a mature and respected organisation whose recommendations and model codes in the field of industrial chimneys are in daily use throughout the world. The organisation still arranges conferences twice a year in major cities.

Roger Bierrum was a long-standing member and had also been President so when we set up Bierrum International Ltd, we asked him to become a consultant for the company so that we could include his name on our letter heads and, in lieu of payment of a salary, we agreed to pay his costs for attending CICIND twice a year.

I started attending regularly after I had been promoted to Contracts Director, but I got much more involved after 2004 when Roger Bierrum nominated me to stand as a Governing Body member and I was elected in 2005. By this time, the Secretary of CICIND was a wonderful character called Klaus Kaemmer and he and I became very close colleagues and friends. Klaus had been the MD of Karrena but had sadly lost his wife, Madelaine, and also retired from the business so Hermann Bottenbruch nominated him as Secretary after the retirement of the previous incumbent, Paul Freathy.

The first CICIND meeting arranged by Klaus was in 2004 in Dublin but it was not a very auspicious start for him because he spent the evening with the Russian contingent of delegates and a vast amount of vodka was consumed. Fortunately, along with some help from Martin Atkins, there were enough of them to carry him to bed that night.

Klaus ran CICIND for 13 years from 2004 to his sad death in 2017 and he transformed the organisation by nearly doubling the membership. He also prepared and published a number of books about the work of CICIND that we sold to interested parties. It is true to say that Klaus was quite a difficult person to work with as there was only one way of doing things and that was his way. We had a few battles over the years but he steered the organisation with a very firm hand on the tiller. CICIND truly became his life's work and his enthusiasm and dedication to the organisation made it the success it is today.

Just after his first conference Klaus married again, to Brigitte who had been his secretary at Karrena, and she accompanied him to all the future conferences. She became very involved with the organisation of the conferences and led the tours arranged for the delegates' partners.



CICIND became as much a social club as a conference facilitator and I got to know many friends in the industry throughout the world. Klaus Kaemmer encouraged partners to come to the conference and the programme of events was expanded to offer dinners and tourist visits to encourage a greater attendance. The networking that was available by the generally well attended biannual meetings was invaluable to Bob and I and there was not much that happened in the chimney world that we did not hear about. Each conference offered twenty to thirty papers on topical subjects informing the delegates of state of the art technology in the industry as well as keeping ourselves at the very top of the knowledge that was available, both in engineering skills and also in the availability of new products. Almost every chimney builder in the world was involved with CICIND and those that were not attending missed out on a great deal.

Having been elected as a Governing Body member, to my huge surprise I was nominated as vice President to serve as President from 2009 to 2013. My term as President finished on the very same day that I retired from business in April 2013. Being President of such a highly regarded professional body as CICIND was a massive privilege and honour and a role I loved from day one and I regard it as one of the most rewarding and enjoyable episodes of my career.

I attended conferences in so many interesting cities around the world from Sydney to Rio, Istanbul to Niagara, each one different and some better than others but the highlights for me must be Cape Town and Istanbul, both of which are fabulous and unforgettable cities.

But then we had a few problems, the first being our proposed conference in Barcelona. The 2010 eruptions of Eyjafjallajökull were volcanic events in Iceland which, although relatively small for volcanic eruptions, caused enormous disruption to air travel across western and northern Europe over an initial period of six days in April 2010 which was just before our conference in May.

All air flights were in chaos so Klaus and I discussed whether to cancel the conference or go ahead. We left the decision until it was a bit late by not finally deciding to cancel until the Monday of conference week. The event was due to start on the Thursday of that week.

Fortunately, the hotel agreed to move the conference to another date one month later so we were not left with massive cancellation costs but unfortunately by the time we had informed everyone that the conference was cancelled, several delegates had already left, including those from the US who were not as badly affected by the dust clouds. Eighteen delegates, including Klaus Kaemmer, arrived in Barcelona on the original date. They all drank a prodigious amount of Pinot Grigio and left at the weekend. We did hold the conference proper one month later although there were still some airline delays.

In January 2009, we booked to have a Governing Body meeting in Cairo as an Egyptian delegate had invited us to visit his city. At that time, I had a contract at El Sokhna near Cairo so I was able to combine the meeting with a site visit - I took Lynn with me as she had never been to Egypt before. It was the time of the Arab Spring and we talked about the current political issues and the unrest with the delegates from Cairo who joined us for dinner on the Sunday evening. Their view was that there would be no trouble in Egypt because it was not in their nature to cause uprisings.

On Monday 24<sup>th</sup> January, we left Cairo and drove to the El Sokhna site on the Red Sea while Klaus and Brigitte went down to Hurghada for a short holiday. After the site visit, we returned to Cairo airport and caught a flight home. On Tuesday 25<sup>th</sup> January, the uprising started in Egypt and all the airports were closed. We were safely home but Klaus and Brigitte were stuck in Hurghada for a week until they met a Condor aircrew who offered to take them back to Germany. Lynn and I were extremely lucky to get out of the city just 12 hours before the start of the uprising.

Our site was shut down and it was several weeks before we could start work again. It was a very worrying time for all of us as we could not contact anyone in Egypt as the internet was down and we had no way of knowing if our crew of men were OK. They also had a problem because they were unable to get any information about the possibility of flights due to the lack of any internet so they were stuck in their hotel rooms for several weeks until the situation calmed down a bit. This was a very difficult and worrying time for us back in the UK particularly as there was so little we could do to help other than just wait for information. We did get word that everyone was safe and the situation soon calmed down. Once the internet was available, we could communicate and sort out flights and we eventually restarted the work.

Probably our worst crisis came when we booked a conference in Venice in 2014. Lynn and I arrived at the hotel on the edge of the

Venice Lagoon and settled into our room. We decided to take the hotel Vaporetto taxi into the town for a bit of sight-seeing but on the way back, we noticed some smoke rising above the strip of land where the hotel was located. The driver said "that is your hotel on fire" - which indeed it was.

The hotel was having some building work done to the cupola on the roof as part of a major refurbishment and it looked like the dome itself was the source of the fire. The staff told us that it would be under control in 5 to 10 minutes, and to stay and wait in the gardens. Fortunately, Lynn decided to run up to the room and retrieve our passports and computer from the safe then, along with many other delegates, we went to the bar opposite to watch the excitement.

The firefighters tried their best but the fire was out of control and it soon became clear we were in trouble. As the land around the lagoon is effectively a series of islands, they do not all have a fire engine let alone firefighters and also there is no piped water so it has to come out of the lagoon.

Several hours and many bottles of wine later, the fire was brought under control enough for the hotel to tell the guests that we each had

five minutes to go and get our luggage and we were to be led to our room by the staff. There were no lights and water was pouring through the ceilings. We got to our room and threw everything into



the suitcases in the dark, then carried them down the three flights of stairs and out of the building where an enormous pile of luggage started to grow. We had actually booked over 70 rooms for the conference and many of the delegates had not arrived. Many were still travelling so taxis were constantly appearing but with nowhere for the guests to stay.

The hotel staff were brilliant and at 6.00pm, they told us to walk down the road as the Welcome Reception had been arranged at another hotel. They said that our luggage would be taken to the Hilton Hotel on another island and transport for both the delegates and the luggage would be arranged. How on earth do you find another hotel with 70 rooms to spare in three hours, but they did.

As promised the Welcome Reception took place in the nearby hotel but with everyone dressed as they had travelled. The canapes and wine flowed and we waited until the transport arrived to take us to the Hilton at 9.00pm. In fact, it was a series of small boats and when we arrived at the Hilton our luggage was piled in the reception waiting for our collection. So with minimal fuss, we were in a hotel which had conference facilities and with our luggage - all was well but without a significant amount of grief on our part, particularly for Klaus who was ultimately responsible for getting accommodation for everyone.

In fact, the conference went very well but the Hilton Hotel only had capacity for us until the weekend when we were to return to our original venue. By this time, the fire was safely extinguished.

However, the place was in a bad state as the carpets were sodden and the ceiling was sagging. Wallpaper was hanging off the walls and it did look a sorry sight. It also smelt suffocatingly of fire damage and dampness which was overpowering and unpleasant. Lynn and I returned to our beautiful room hoping that our last two nights would be undisturbed but as we lay on the bed, we heard a drip coming from the ceiling onto the end of the bed which increased to almost a torrent of water. It was raining outside and apparently the fire damage had destroyed the roof flashings. Off we went again to another, not nearly as beautiful, room.

The whole adventure did give us a wonderful story to tell the family when we arrived back into the UK and I have to say, the event could have been a disaster but the hotel staff, together with Klaus Kaemmer, worked miracles and managed to salvage the conference so all was well in the end.

In 2013, my term as President of CICIND came to an end, although I stayed on the Governing body as a Past President. On my final night, I was at the conference in Istanbul hosted by Endem. We had the most wonderful gala dinner at the Maidens Tower in the middle of the Bosphorus on the Friday night, the 4<sup>th</sup> May, which happened to be at the exact time that my daughter gave birth in Doha to our grandchild, a baby girl called Meltem. My daughter’s husband is Turkish so it was very apt that I should be in Istanbul that night and along with all the delegates, I proposed a toast to the birth to wet the baby’s head.

Secretary Klaus had an accident while he and Brigitte were on a New Year’s holiday in Venice in 2014. He badly damaged his neck which, although he wasn’t immobilised, caused him some serious issues and we did discuss the implications of it being the end of Klaus Kaemmer’s time as Secretary. In addition to his accident, he had already suffered pancreatic cancer from which amazingly, he recovered. As far as Klaus was concerned, he was fine and had no intention of stepping down. It was taken as read that I would take over as Secretary on his retirement, as I had been so involved with the organisation and it would be an ideal job for me in my oncoming retirement.

After a lot of thought, I decided not to take the post, much to everyone’s surprise. I did not want to be trapped into a full-time job

and I also realised that Klaus Kaemmer’s time as Secretary was a very hard act to follow. By 2016, Klaus had agreed to retire and we held a wonderful celebratory evening at the May Conference in Mainz in Germany, which was his home town. His family, many friends and delegates attended and he was given a fantastic evening of speeches and presentations. However, Klaus did not actually leave his post until later as the chosen successor, Hermann Hoffmeister, was not available until Jan 2018 so Klaus agreed to continue until then.

In August 2016, Klaus had another accident when he fell down some stone steps and damaged his neck and chest yet again. This time it was more serious and he lost the ability to swallow, so he needed a tube inserted into his stomach in order to receive food. He was unable to continue with his role so I had to step in and take over for 18 months until Hermann could become Secretary. The accident occurred just before a joint conference in Rotterdam, so it was a very difficult task to pick up where Klaus had stopped, however his records were good and we managed to cope and the conference went ahead. It did not stop him calling me on a daily basis and offering advice about the organisation of the next conference. He was also adamant that he would attend but it was not to be.

Klaus Kaemmer sadly died in March 2018 from complications arising from his accident. I had suffered a similar accident in January 2018 when I fell and broke my neck, so I was unable to attend the funeral. Hermann Hoffmeister took over and a new era of CICIND arrived. Rick Lohr, Klaus Kaemmer and I, three stalwarts of CICIND, had all had similar accidents of dislocating our neck vertebrae – almost enough to form a club.

Looking back over my 24 years of involvement with CICIND, I value the tremendous experiences Lynn and I had with travelling to so many places and all the many friends and acquaintances that we made throughout the World. Like all organisations, it has had to change with the times and we have now changed the name to International Construction rather than International Chimneys to recognise that the chimney market has all but died out. We have also held conferences combined with the Cooling Tower industry as so many of our delegates are involved with both. The current Covid-19 situation has not helped us as we have had to cancel two conferences in 2020 and are about to embark on our first virtual conference. However, CICIND will survive and hopefully flourish when we finally come out of the Pandemic.



## New Members



### **Karsten Grasemann**

Is the technical director of Aero Solutions SAS. He studied mechanical engineering with the specialization of computer science in engineering at Ruhr-Universität Bochum focusing on simulation, numerical calculation, automation and robotics. He started his industrial career as a research engineer at GEA Energietechnik GmbH in 2006 responsible for numerical calculations and software development. In 2013 he received his Doctoral degree for the development of a technical swarm algorithm to solve pressure drop minimized tube-layouts in power plants.

Since 2015 he joined Aero Solutions SAS as the technical director and he is responsible for the R&D-, engineering- and IT-departments.



### **Mattia Panza**

Mattia Panza, born in 1990, is an Italian civil engineer. In 2015 he graduated from University of Bergamo in Structural Engineering with a Master's degree with a particular interest on the seismic behaviour and the seismic retrofitting of the existing buildings.

He joined Chimney and Refractories International S.r.l. immediately after the completion of university career. Firstly, he was involved in the design of reinforced concrete chimneys under the guidance of CRInt technical department for a period of two years.

Then, he decided to deepen his passion about the construction field operating as Project Manager for several projects into the Middle East and South East Asia.

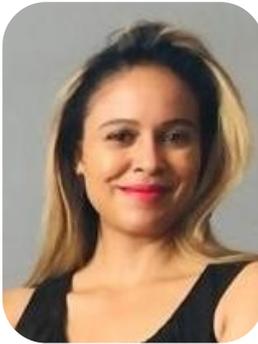
Mattia is passionate about soccer, mountain hiking and he likes to visit the European cities of art and history.



### **Unai Rodríguez,**

Mr. Rodríguez is a Spanish born Technical Industrial Engineer who in 2010 co-founded Accesus Plataformas Suspendidas, S.L. with two more coworkers. Accesus offers standard products and special solutions related to suspended platforms at heights and difficult access places, specially in industry all over the world. Prior to this he worked for around 10 years in technical departments as a manager in companies of the sector. He is married with two young children and enjoys spending time cycling and with family.”

## New Members



### **Anthea Dennis**

Anthea has over eleven years' civil engineering experience. Seven years' experience for a global Chemical and Energy Industry Leader. Her formative four years' experience was developed in the civil and urban engineering infrastructure space. She currently leads a team of civil engineers, and manages an extensive structural asset portfolio which includes concrete cooling towers, concrete chimney smoke stacks, silos, dams, steel structures, amongst others. The objectives of leading the team of talented Civil Engineers is to transform a plant support department into a world class partnership. A partnership in converting coal and gas into fuel, and useful chemicals through the safe, smart and effective use of civil / structural assets to drive these goals. Through the partnership she is responsible to identify and provide inputs on structural engineering standards, regulations and risks. She is responsible for optimizing the use of operational funds, effectively plan resource utilisation combined with exploring the use of new technologies.

Responsibilities include:

- Ensure governance of structural engineering practices including monitoring and audits
- Manage engineering discipline interface to ensure quality service delivery
- Develop life cycle analyses and justify life extension strategies
- Interpret OSH Act, National (and international) Civil Engineering Codes and specifications, Sasol specifications and other health and safety requirements and set site-wide work procedures to achieve required compliance
- Accountable for the quality management of engineering solutions for projects and ensure delivery on technical intent
- Ensure discipline specific quality assurance such as: vendor selection, technology selection, technical specification reviews, client design reviews, punching, End of Job documentation reviews

She is committed to her own professional development and actively encourages and works on inspiring individual growth amongst her peers. She drives high levels of synergy and collaboration within teams.

# Future Conferences - Preview



Dresden: 20<sup>th</sup> to 23<sup>rd</sup> October 2021

Sponsor: MC Bauchemie



*Zwinger Dresden*



*Frauenkirche Dresden*



*Dresden Castle*



*Semperopera Dresden*



*August der Starke*



# Future Conferences - Preview



New Orleans: 18<sup>th</sup> to 21<sup>st</sup> May 2022



Sponsor: ERGON ARMOR



*Hotel Le Pavillon In the French Quarter*



*Bourbon Street in the French Quarter*



*Le Pavillon*



*Musical Legends*



*A streetcar in New Orleans*



# Future Conferences - Preview



Joint Conference ICCT Shanghai    October 2022

Sponsor: TONGJI UNIVERSITY



*The Jade Buddha Temple from 1882*



*Nanjing Lu Shopping Mile*



*The Bund*



*Above the clouds*



*The Yuyuan Garden - French Quarter Area*



*Zouzhuang*



*Cherry blossoms at Tonghi University*

# Future Conferences - Preview



CICIND Conference Florence 17<sup>th</sup> - 20<sup>th</sup> May

Host: UNIVERSITY FLORENCE



*Palazzo Vecchio*



*Duomo cupola*



*Perseus at Piazza della Signoria*



*Palazzo Pitti,*



*Young Michelangelo*



*Venue. Istituto degli Innocenti*



*Conference Room: Salone Brunelleschi*

	<b>Activity Report</b> January 2021	<b>Committee</b> <b>Lifetime Management</b> <b>for Chimneys</b>
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**Committee Chairman:** Andreas Harling

**Committee Members :** Christoph Guehmann, Reinhard Martin, Gary Eastman, Andrew Galbraith, Bohumil Jezek, Martin Breddermann, Heiner Stahl, Michael Beaumont, Fernando Ferrero

## GUIDELINE - update

The Cicind Lifetime Management Committee was founded during the Graz Conference in May 2018. The preferential goal is the development of a new guideline "Lifetime Management" as a replacement for the previous Maintenance Guideline. The new guideline is intended to serve the worldwide operation of steel, brick and concretes chimneys after the transfer of responsibility from the builder to the operator.

After 2-3 meetings of the group per year, the draft of the guideline has been finalized in August 2020, with the following structure.

- 1 Introduction
- 2 Definition of Lifetime Management
- 3 Terminology
- 4 Implementation of lifetime management (PDCA)
- 5 Planning and construction
- 6 Maintenance
- 7 Survey and Inspection
- 8 Operation Duration
- 9 dismantling, demolition

The draft is currently being revised. The guideline is to be approved at a further meeting of the group in September and the final version presented at the Cicind meeting in Dresden in October 2021.

*Andreas Harling*

	<b>Activity Report</b> January 2021	<b>Committee</b> <b>Duct</b>
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**Committee Chairman:** Denis Radecki

**Committee Members :** Hans Ruscheweyh, Yasser Naguib, Jihui Wang, Steven Reid, Vic Bochicchio, Michael Kociniak, David Anderson, Bob Brady, Michael Angelides, John Davenport

There have been no meetings since the last Governing Board meeting. A draft of Chapters 0 to 9 was assembled into a single document (copy attached) in November. This draft will be distributed to committee members for comment in June.

I continue to be occupied with the revision of ACI 307-08. That committee has had a meeting every week to two weeks for the past 2 years, but seems close to finally concluding its work. When that task is wrapped up, I should be able to put more effort into the duct model code.

*Denis Radecki*



**Committee Chairman:** Hans-Juergen Niemann

**Committee Members:** Charles Goddard, S.O. Hansen, Steven Reid, Hans Ruscheweyh, Ashwini Oke, Francesca Lupi, Rüdiger Höffer

The last meeting of the Wind Committee took place at the 90<sup>th</sup> CICIND Conference in Graz 2018. This Activity Report briefly surveys what has been going on since then in the topic Wind.

At the Graz meeting, two topics mainly lead in the discussions regarding wind effects on chimneys:

(i) *Structural behaviour under Along-Wind Action:* The stress distribution under the action of along-wind loading may deviate from the linear distribution assumed by the beam theory. The non-linearity induces higher stressing of the structure. The parameters dominating the effect are rather clear. However, concrete criteria for assessing the importance of the effect are not yet available in design practice. They may potentially be developed and included the CICIND model codes for chimneys.

(ii) *Cross wind vibrations induced by periodic vortex excitation (VIV).* This topic dominated the discussions. It is important, because it may become leading in the design of chimneys, particularly regarding fatigue. Details are summarised as follows:

The discussion at the meeting focussed on the pros and cons of available models to predict the amplitudes of VIV. The CICIND Model Codes utilize the Vickery and Basu model, which is based on the spectral method and determines the peak displacements via its standard deviation. It treats the aeroelastic interaction as a negative aerodynamic damping. Its magnitude depends on the rms vibration amplitude. The approach includes a characteristic curve relating the two parameters. Investigations supported by CICIND showed that the amplitudes calculated based on the Model Code Commentaries may be rather conservative compared to those obtained from experiments in wind tunnels or observations in full-scale. A new characteristic curve proposed recently improves the predictability of the VIV-amplitudes. The following activities regarding VIV were envisaged at the meeting:

- 1) Wind tunnel experiments on a circular cylinder applying the forced-vibration technique to gain additional insight as to the relation between the aerodynamic damping and the rms-displacement. Francesca Lupi of the Bochum Group and Svend Ole Hansen's team were invited to perform the tests jointly at Svend Ole Hansen ApS in Copenhagen.
- 2) Introduction of a revised curve in the complete CICIND model as contained in the Model Code Commentaries. The extended method - that solves the dynamic equation of motion in resonance and includes the aeroelastic interaction through the negative aerodynamic damping - will be developed further.
- 3) Additional research concerning modelling the aeroelastic response of slender structures to vortex-induced vibrations in view of fatigue analysis, including free vibration tests.

Thanks to the dedication and commitment of the committee members, an important part of this ambitious work programme could be accomplished.

The Eurocode for wind loading EN 1991-1-4 is presently being revised. Regarding VIV, the draft proposal corresponds in principle to the Vickery-Basu model.

The effect of flow interference in groups of chimneys was addressed at the Graz Conference and at the Wuppertal Online Conference by our Indian colleague Rishav Rajora. His research deals with tower groups where the distance is beyond 10 diameters. The Scruton number tested is high, so that mainly the forced vibration regime of VIV is covered. Rishav shows that the interference effect on VIV can be considerable even at a large distance. The taper of the tower has a significant effect as well.

In the range of closer distances, aeroelasticity becomes more important for VIV when the Scruton number is small. It may induce interference galloping of 2 or more towers. For this situation, the Eurocode stipulates a calculation method for the critical wind speed beyond which galloping occurs. More research is needed in this field.

Most of the knowledge considered is based on wind-tunnel experiments. In such tests the Reynolds number is smaller by a factor of several hundred compared to the full-scale condition. For circular cross-sections, the Reynolds number disparity can have a considerable effect on the aerodynamic parameters. It can be compensated by surface roughness of the wind tunnel model. The requirements and test procedures will be highlighted at one of the next meetings.

In view of the new orientation of CICIND towards INDUSTRIAL CONSTRUCTIONS, the Wind Committee will collect related topics and, if appropriate and desired, extend its activities beyond chimneys accordingly.

*Hans-Jürgen Niemann*

# Virtual CICIND Conference

Host: Hadek Protective Systems, Rotterdam

Thursday, 20<sup>th</sup> May 2021

11:00	Welcome by the President	Albert de Kreij
11:05	Welcome by the Secretary and further instructions	Hermann Hoffmeister
11:15	Design & Construction of a Flue Gas Duct System from the Chimney to the Cooling Tower	Michael Angelides AMTE, Greece
11:40	Validation of current design Concept for RC-Chimneys near openings via non-linear shell analysis	Franziska Wehr EZI – Ingenieure GmbH, Germany
12:05	Project of inner chimney demolition using suspended platforms and a robot	Ramon Esteve Accesus, Spain
12:30	Gas turbine stacks – specifics, design and recommendations	Michal Kociniak Dominion Europe
12:55	Finish first Section	

12:55 Lunch Break

15:00	Recent Advances in the Development of Liner Technologies for High Speed Wet Stack Operation	James M. Daniel Alden Research Laboratory, MA
15:25	Ten Pounds of Sausage in a Five Pound Sack	Rick Lohr, G. Gardner Youngs- town, New York
15:50	Reducing air toxic impact from power plants startups through CFD-assisted design of chimneys	Paolo Zannetti, Guiseppe Bucci, Envirocomp Institute, California
16.15	Finish	

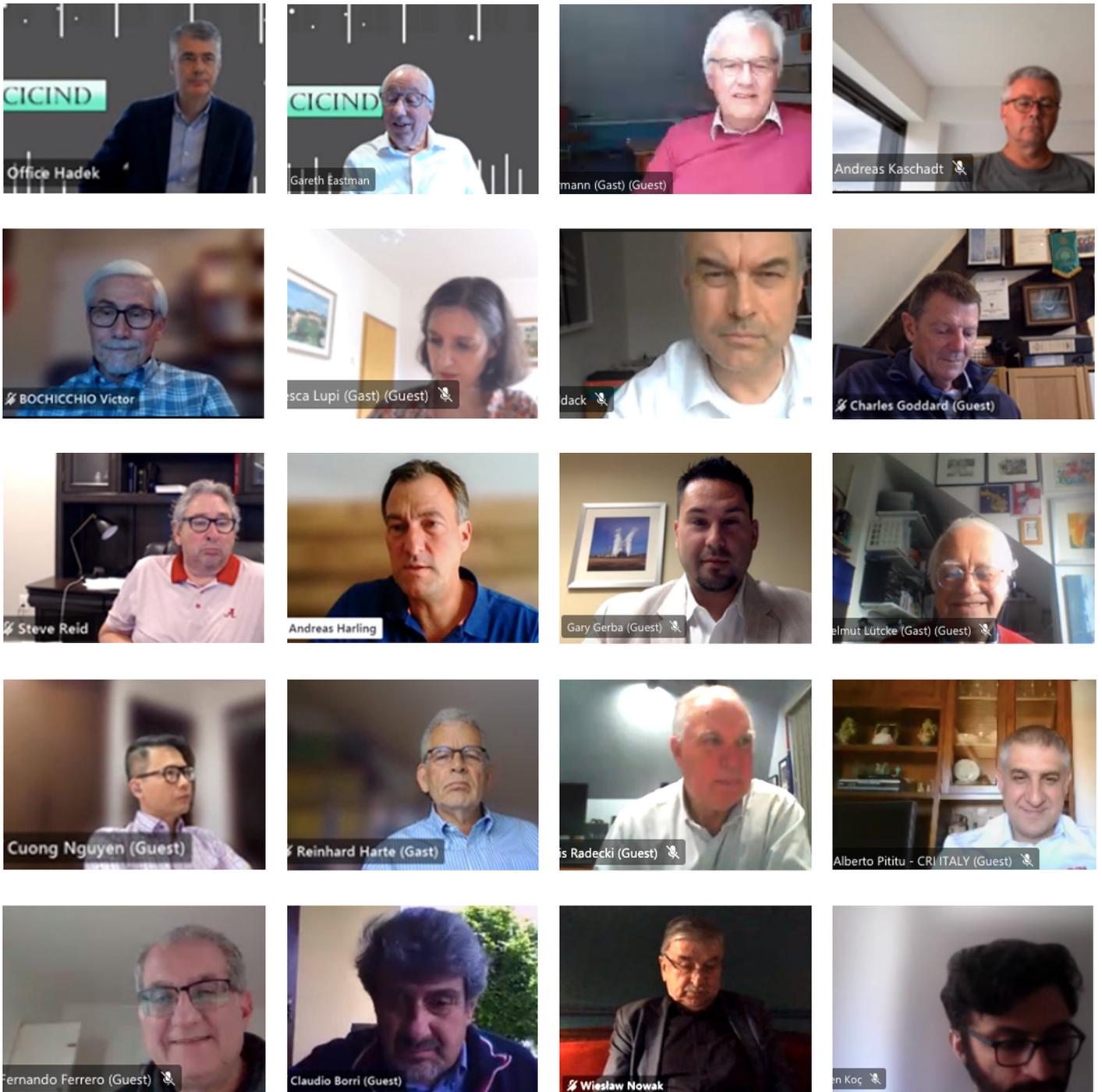
Friday, 21<sup>st</sup> May 2021

10:30	Welcome by the Secretary and further instructions	Hermann Hoffmeister
10:35	Inspection improvement – Application of new VR/AR technologies within building and concrete inspection	Karsten Grasemann, Alfred Heimsoth Aéro Solutions SAS
11:00	Safe access on tall structures	Wieland Beine Sylotec GmbH, Germany
11:25	Surface Protection of a flue in wet-stack operation	Reinhard Martin MC Bauchemie, Germany
11:50	Q&A: How is the pandemic affecting your business	Gary Eastman (Moderation)
13:00	Normal General Assembly (NGA) for CICIND Members	Hermann Hoffmeister
14:15	Finish	

# The Technical Meeting

Because of the Corona pandemic, the meeting had to be held virtually again. This time it was organised by Hadek Protective Systems in Rotterdam. We would like to thank Albert de Kreij and his team for the fantastic organisation and running of the event. Many members and guests attended the conference, which again presented interesting contributions.

*CICIND audience in the whole world focused at the Video Conference*



*... and many more*

*Zoom-screenshots may 2021*

# CICIND VIRTUAL CONFERENCE ROTTERDAM – 20 and 21 May 2021

## The Pandemic – Question and Answer session Moderator – Gary Eastman

The purpose of the session was to elicit the views of the delegates on the effect of the pandemic on their businesses and whether this will result in long term changes to their methods of working.

Albert de Kreij had been a very frequent user of international flights up until early 2020 and since then he has had very few overseas trips relying mainly on Zoom to communicate with customers and staff.

He said that his major problem was the inability to send his inspection teams to site due to the lockdowns together with many jobs being cancelled or delayed.

His view is that he will return to full time working at his offices as working from home supresses creativity when staff are not together.

Reinhard Martin said that the pandemic had allowed his company to quickly adapt to the new circumstances but zoom will never replace face to face meetings as these are sometimes crucial.

Helmut Luetcke explained some of the problems associated with home working from the IT perspective. There is a problem with compatibility and also using equipment with unlicensed software at home. Andreas Harling reported that his company had been fined last year for this breach. Good internet speed is essential when working from home as large files may need to be shared.

He warned about the problems of using Dropbox where several people can amend a document online at the same time.

Security is an issue and many companies will not allow Zoom to be used.

Vic Bochicchio commented that hiring staff virtually can lead to problems when they are eventually needed to work in the office. It is very difficult to interact and get to know new staff when they are at home and not in the office environment.

The Greek economy suffered badly with the recent financial crisis and this was quickly followed by the pandemic. Michael Angelides

was asked about the effect on his business and his response was that many jobs had been stopped but the biggest problem is cashflow as everyone is holding onto cash.

However, he can see things improving so he is hopeful for a brighter future.

Piet Willemsse from South Africa told the delegates that the situation there was difficult as Government spending had stopped and many major jobs were postponed. Escom have many problems and they are not currently carrying out any repair or inspection works. It is the same situation in mining as everyone is holding onto capital.

However, he was positive and felt that the situation will improve in the medium to long term.

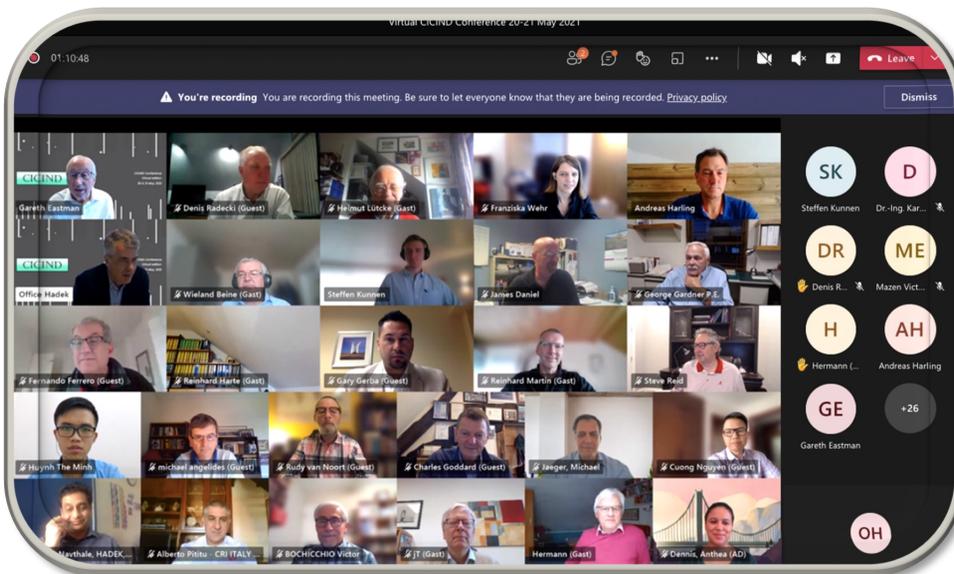
Wieslaw Nowak told us that he had resolved to keep all his staff employed despite the difficulties. He told us about a recent project in South America where he had to put 71 staff into hotels for two weeks before they could start work.

He said that most, but not all, clients had offered to reimburse him for the additional isolation costs.

He said that although he had received some Government support, this was not sufficient to cover his extra costs for staff lay-offs.

Reinhard Harte said that one positive outcome was that the roads are much quieter so travel to projects in Germany was generally easier.

Overall, despite the difficulties that everyone has seen in the last 15 months, delegates were positive about the outcome and generally of the opinion that there would be little fundamental change to their way or operating.



*Gary Eastman*

# Speakers



Michael Angeli...

*Michael Angelides*

**Design & Construction of a Flue Gas Duct System from the Chimney to the Cooling Tower**



*Franziska Wehr, Reinhard Harte*

**Validation of current design Concept for RC-Chimneys near openings via nonlinear shell analysis**



*Ramon Esteve, Unai Rodriguez*

**Project of inner chimney demolition using suspended platforms and a robot**



Michal Kociniak

*Michal Kociniak*

**Gas turbine stacks – specifics, design and recommendations**



*James M. Daniel*

**Recent Advances in the Development of Liner Technologies for High Speed Wet Stack Operation**



George Gardner P.E.

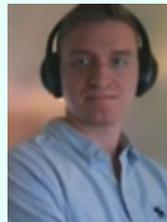
*Rick Lohr, George Gardner,*

**Ten Pounds of Sausage in a Five Pound Sack**



*Paolo Zanetti, Giuseppe Bucci*

**Reducing air toxic impact from power plants startups through CFD-assisted design of chimneys**



*Stefan Kunnen, Karsten Grasmann*

**Inspection improvement – Application of new VR/AR technologies within building and concrete inspection**



*Wieland Beine*

**Safe access on tall structur**



Reinhard Martin (Gast) (Guest)

*Reinhard Martin*

**Surface Protection of a flue in wet-stack operation**



Gary Eastman

*Gary Eastman*

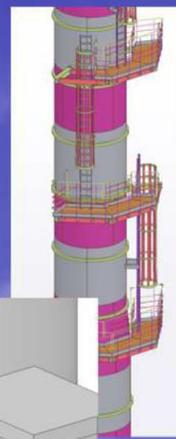
**Q&A: How is the pandemic affecting your business**



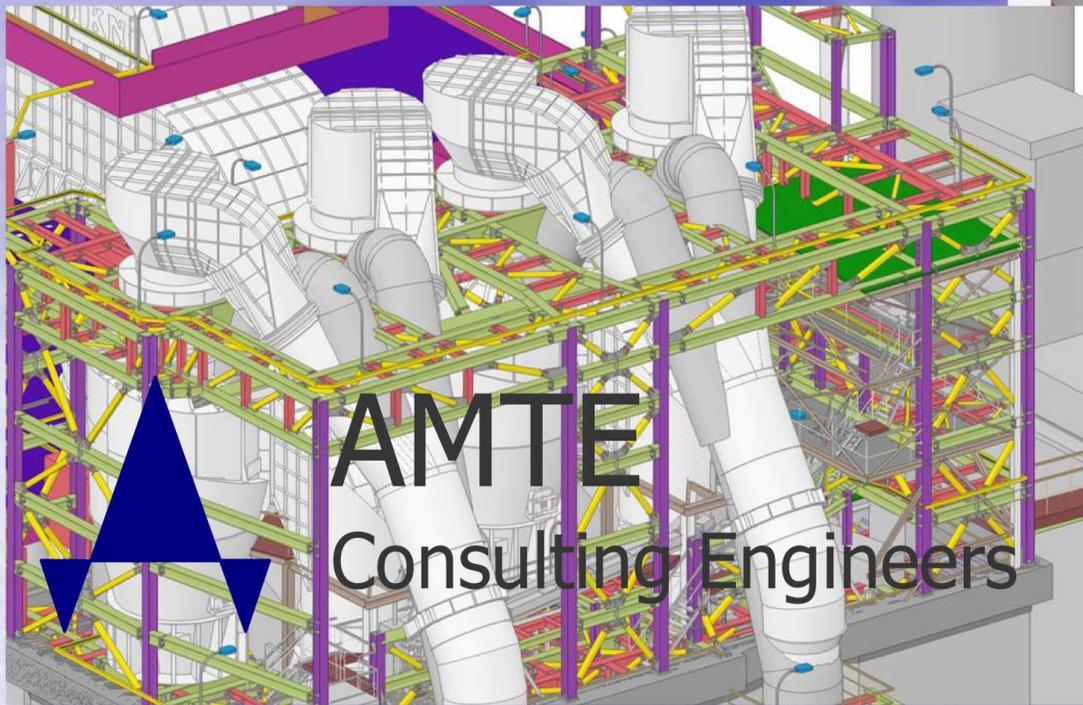
Bang Pakong Cooling Tower, Thailand



Enemalta offshore LNG, Malta



Bocamina chimney, Chile



**AMTE**  
Consulting Engineers



Steel Cooling Tower, Russia



Preheating Tower, Greece

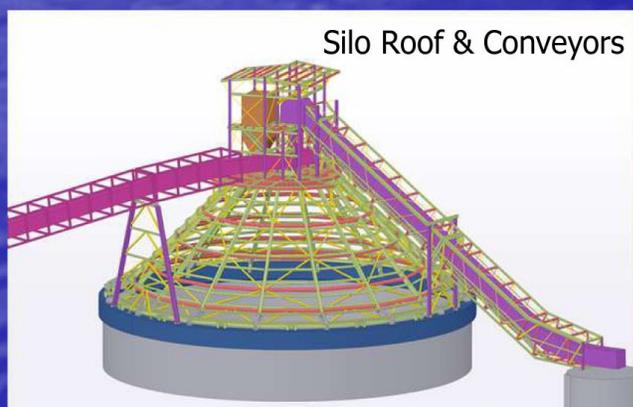


Flue gas ducts

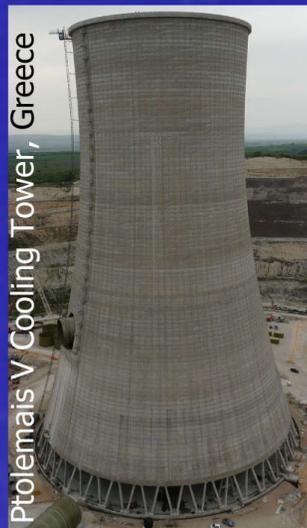


Athens International Airport

Design of special industrial structures  
Design of Seismic Strengthening  
Design of building projects



Silo Roof & Conveyors



Ptolemais V Cooling Tower, Greece



Meliti Power Plant, Greece

2004 / 2 / 18



### Michael Angelides

Michael is a Greek Civil Engineer with B.Eng. and a M.Eng from McGill University, Canada. In Montreal he worked at orthopedic implant and at satellites design. He returned to Greece in 1989 and joined AMTE. Since 1993 he is the managing director of AMTE, a consulting company specializing in the design of all kinds of industrial projects.

# Design & Construction of a Flue Gas Duct System from the Chimney to the Cooling Tower

*Michael Angelides*  
AMTE Consulting Engineers, Greece

## 1. Introduction

The work presented is part of the Flue Gas Desulphurization retrofit project, currently under execution at the Agios Dimitrios V Thermal Power Plant, in the district of Macedonia, in north-western Greece. The Plant owner is the Public Power Corporation of Greece (PPC) and the EPC contract for this project was awarded to Avax, a Greek contractor. The Process designer was Sirius (Finland) and the scope carried out by AMTE and presented hereunder consisted of the following:

- Conceptual Design of the Flue Gas and Clean Gas lines.
- Detailed design of the flue gas ducts and their supporting structures.
- Detailed design of the Absorber.
- Detailed design of the discharge inside the Cooling Tower.

The Agios Dimitrios V power plant was built during the period 1993-1995. It is the newest and probably the only one of the 5 units to be retrofitted with an FGD system, since the older units will be gradually decommissioned, as part of the plan for reduction in operating lignite fired power plants.

As can be seen in the following image, the task involves picking up the flue gas at the 2 chimney inlets, combining it into one duct and lead it to the Absorber. The treated gas will then be led through an opening to be created in the Cooling Tower shell for final discharge at the centre of the Cooling Tower.

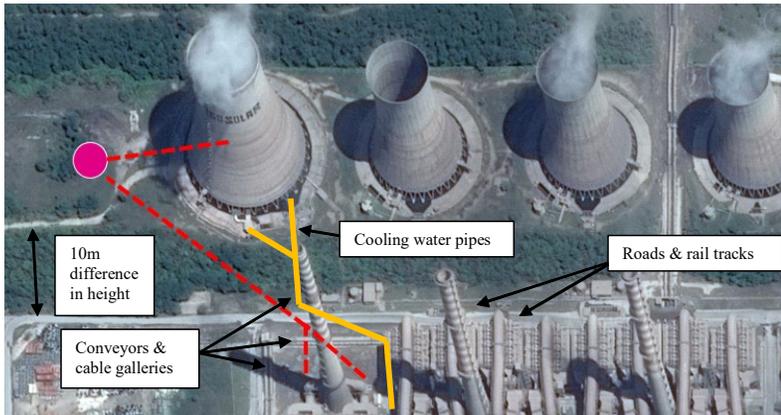


*Figure 1.1: Overview of the FGD installation region (photo from Google Earth)*

As is usually the case with interventions in existing plants, there are several complications along the routing of the flue gas duct system:

- The cooling water pipes running from the plant to the cooling tower need to be avoided.
- Existing roads and a rail track need to remain operational.
- Existing underground cable galleries and above ground conveyors need to be avoided.

Finally, the existing cooling tower lies 10m above the level of the remaining plant.



**Figure 1.2: Complications & obstacles to the Duct routing (photo from Google Earth)**



**Figure 1.3: View of the project area (photo taken from the cooling tower basin wall)**

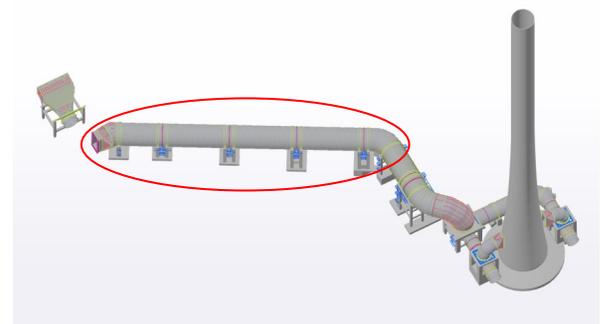
## 2. The Flue Gas Ducts

The required duct cross section was in the order of 80 to 82 m<sup>2</sup>. A circular duct with 10.2m diameter has a cross section of 81.7m<sup>2</sup> and a circumference of 32.044 m, while a square duct with 9.0m sides has a cross sectional area of 81.0 m<sup>2</sup> and a perimeter of 36.000 m. This means that the choice of a square or rectangular duct would result in 12.5% larger duct perimeters. The rectilinear distance to the Booster Fan is in the order of 160m, so that a square duct would require 700m<sup>2</sup> additional perimeter surface, and correspondingly higher quantities for steel plating, steel stiffeners, insulation and cladding. Furthermore, the Project specifications did not allow internal bracing, and, therefore, a square or rectangular duct would require heavy external moment frames for strength and stiffness. In view of the above, circular ducting of 10.20m diameter has been selected.

The next step in the duct system conceptual design was to select the optimum single duct element length. A single duct element is a structurally determinate system separated by expansion joints from the upstream and downstream duct elements. An iterative investigation was carried out, in order to determine the maximum feasible length of a structurally independent flue gas duct segment. Several duct lengths were investigated and the corresponding demand on supports, duct thickness and erection weights were calculated. A duct segment length of about 30m was selected for the following reasons:

- It allows the duct shell thickness to be kept at the minimum requirement of 6 mm.
- It allows for a reasonable arrangement of reinforcements around the support points.
- It is within the limits of erection and hoisting capabilities.
- It allows for a minimum number of supporting structures.

Fig. 2.1 depicts the flue gas duct routing, while Fig. 2.2 is a photograph from the erection of the straight duct elements (highlighted in Fig. 2.1). Reinforced concrete structures were selected for the supports between independent duct elements, in order to provide the necessary stiffness and to withstand the high seismic overturning moments.



**Figure 2.1: Overview of the Flue Gas Duct routing (erection of highlighted segments shown in Fig. 2.2)**



**Figure 2.2: Erection of straight duct elements**

There were some special cases to be addressed in the course of the design of the flue gas ducts. The existing chimney inlet ducts are supported on steel structures. For the purposes of the FGD retrofit, these inlets need to be modified, in order to allow the flue gas to either enter the chimney or bypass the chimney and flow to the Absorber. According to current Greek regulations, any intervention on existing structures requires their upgrading to current seismic design codes. All these works need to be carried out during a predefined 3-month plant shutdown, with a heavy daily penalty for delays.

In order to overcome this difficulty, it was decided to fully replace the inlet duct structure. The support structure was built from reinforced concrete around the existing steel support, in order not to involve plant shutdown time during these works. Therefore, the necessary works to be performed during shutdown were limited to the dismantling of the existing inlet ducts and the erection of the new ducts.



Figure 2.3: Existing inlet (top left), Designed solution (top right) & Erection (bottom)



Figure 3.2: Absorber construction.

main segment was a prefabricated steel beam with a concrete jacket and polypropylene embedded lining. The two end segments were steel beams bolted to embedded female threaded anchors and single-pin connected to the main segment. The end segments were subsequently provided with a grout jacket and polypropylene lining “pushed” into the fresh grout after their erection.



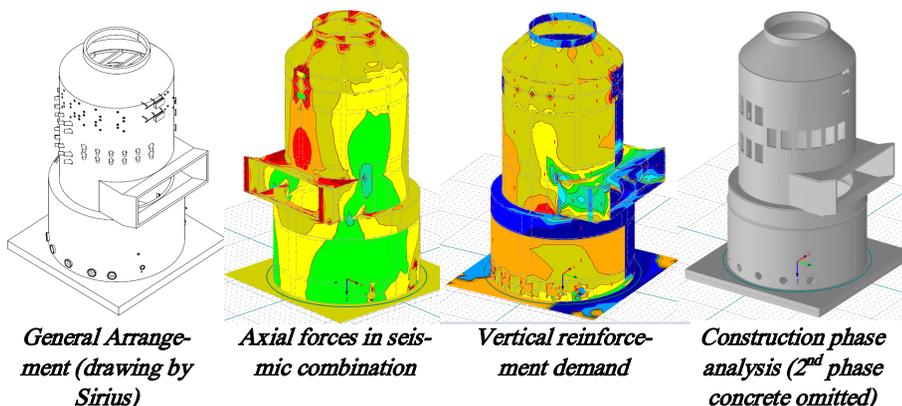
Figure 3.3: Absorber. Erection of internal precast beams.

### 3. The Absorber

A concrete structure with internal liner has been specified (polypropylene liner generally, and special metal alloy at the inlet and around the inlet opening). The inlet opening dimensions are 5200mm high by 15300 mm wide, in an 17000 mm diameter shell. This, along with the very large number of required openings led to high seismic stressing of the shell and required special stiffening and strengthening measures (part of which were realized through the utilization of the inlet side walls and the inlet bottom as stiffeners).

Several of the openings required additional reinforcement measures and large embedded elements, which led to the need for 2<sup>nd</sup> phase concreting (after the completion of the climbing formwork construction) and to the corresponding construction phase analysis. Fig. 3.1 illustrates some of these difficulties.

A large number of internal beams and corbels were required, in order to support equipment and ducting and to allow maintenance access. In order to facilitate erection and absorb construction tolerances the beams were erected in 3 segments each (see Fig. 3.3). The



3.1: Absorber design.

#### 4. Clean Gas Duct Line

The Clean Gas Duct consists of 3 segments separated by expansion joints (see Fig. 4.1): A short 90-degrees bend on top of the Absorber, a vertical segment with two 90-degrees bends supported by a steel tower and a longitudinal segment with an end 90-degrees upwards bent for the clean gas discharge at the centre of the cooling tower. The longitudinal segment is vertically supported at 3 locations: one on a new concrete structure outside the cooling tower, one at a location of distribution channels support (A-frame) inside the cooling tower and one at the centre of the cooling tower. No loads are transferred to the cooling tower shell and no horizontal loads are transferred to the middle support inside the cooling tower, since these would require extensive reinforcement measures. The full seismic longitudinal force is taken by the new concrete structure outside the cooling tower, while the seismic transverse load is shared by the new concrete structure outside the cooling tower and the new structure required for the support at the centre of the cooling tower.

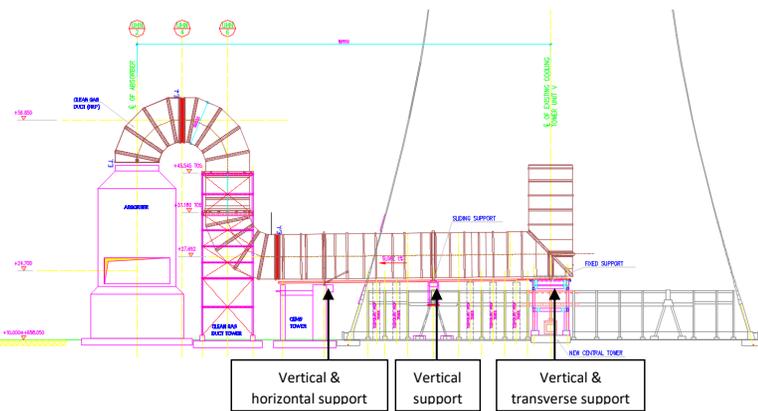


Figure 4.1: Preliminary design of Clean Gas Duct Line.

The main challenge here was the fact that this specific cooling tower has two risers, none of which is located at the center of the cooling tower. It is therefore necessary to construct a new tower from the ground level to the level of the clean gas duct support. This structure is required to be a reinforced concrete, since no steel structures were allowed inside the cooling tower, even if they are protected by coating or sprayed concrete. These works are necessarily to be executed during the 3-month shutdown period.

It was therefore decided to proceed as follows:

- Use the existing crane foundation (built 27 years ago, during the construction of the cooling tower), for the foundation of the new tower.
- Construct 4 corner plinths dowelled to the existing crane foundation, in order to allow the anchorage of the vertical reinforcements.
- Erect the new tower from precast concrete elements, with dimensions allowing their passage between the existing concrete precast support elements and the ducting.
- Since the needed outline of the top platform of the new tower significantly exceeds the perimeter of the existing crane foundation, it was not possible to create reliable seismic moment connections between the top platform precast elements and the tower precast columns. It was therefore decided to create moment resisting frames in 2 directions within the perimeter of the crane foundation and to position the top platform on top, as a secondary structure, connected to the moment resisting tower through simple shear connections.

Fig. 4.2 illustrates the design concept and shows the obstructions from the existing structural and equipment elements and Fig. 4.3 shows the erection of the structure and the grouting of the precast moment connections.

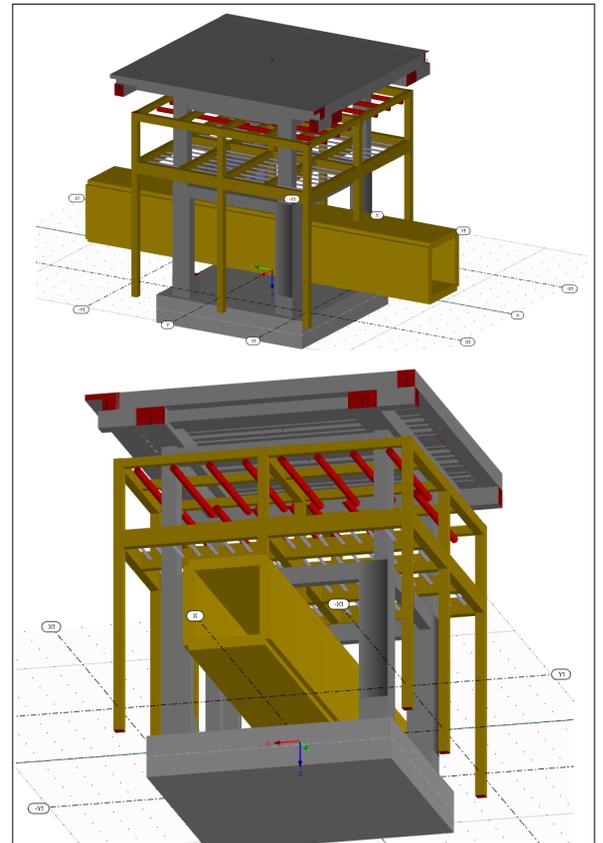


Figure 4.2: New central tower design concept.



Figure 4.3: Erection of new central tower



**Franziska Wehr**

Franziska Wehr was a Teaching and Research Assistant at the School of Architecture and Civil Engineering, University of Wuppertal from 2012 to March 2021. Her Areas of Expertise are finite element simulation of soil-structure-interaction and of RC plate and shell structures, especially of concrete chimneys and natural draft cooling towers. Since April 2021 she is a project engineer at EZI-Ingenieure GmbH, Solingen.



**Reinhard Harte**

Reinhard Harte was Full Professor for Statics and Dynamics at the School of Architecture and Civil Engineering, University of Wuppertal. He was founder and CEO of Krätzig & Partner GmbH, Bochum, and today is still one of its associates. He is Certified Expert on Structural Safety and on Fire Design and member of various committees, such as Chairman of IASS-Working Group “Cooling and Solar Updraft Towers”, Chairman of the VDI Guideline Committees “VDI 6201 – Software-based Structural Analysis” and VDI 6210/9 – Structural Demolition Analysis”, Member of VGB Scientific Board “Chimneys and Cooling Towers”; Member of Editorial Board of VDI “Bauingenieur” and of Acta Polytechnica of CTU Prague and Honorary Expert of DFG and DAAD.

# Findings of CICIND R&D-Project „Validation of Current Design Concept for Concrete Chimneys near Openings via Nonlinear Shell Analysis“

*Franziska Wehr, EZI-Ingenieure GmbH, Solingen  
Reinhard Harte, Krätzig & Partner GmbH, Bochum*

## 1. Introduction

This Paper gives a short summary of the R&D Project which was finished at the end of 2020 and financed by CICIND. Its intention was to validate the CICIND Design Concept for RC chimneys near Openings, which is currently based on beam models [1, 2].

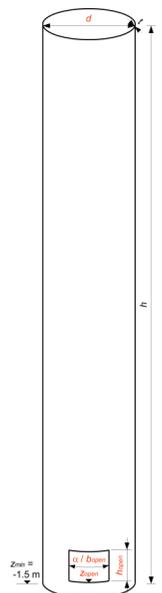
According to CICIND Model Code [1], the amount of vertical reinforcement lost due to an opening in the chimney wall must be replaced to the sides of the opening. Above and below the opening additional reinforcement must be placed to cover tensile forces and bending moments caused by the opening. The value of those forces and moments can be calculated via two simplified equations according to CICIND Model Code [1].

In the R&D Project [3], a parameter study with multiple parameter variation has been performed on a reference chimney with a height  $h$  of 149.5 m and a wall thickness  $t$  of 35 cm in order to validate this design concept.

## 2. Parameter Study

For the described chimney, the following variations geometry parameters are used for the validation among others (Figure 1):

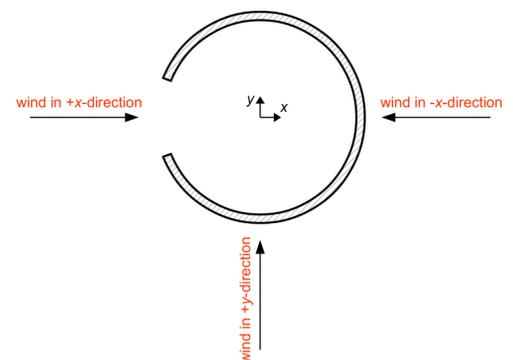
- Variation of the diameter of the chimney  $d$ :
  - $d = 5 \text{ m}, d = 7 \text{ m}, d = 8 \text{ m}$ : representing beam like chimneys ( $h/d > 17$ ) according to [3].
  - $d = 15 \text{ m}, d = 25 \text{ m}$ : representing shell like chimneys ( $h/d \geq 17$ ) according to [3].
- Variation of the opening angle  $\alpha$ :  $\alpha = 10^\circ, \alpha = 20^\circ, \alpha = 30^\circ, \alpha = 40^\circ, \alpha = 50^\circ, \alpha = 60^\circ$ .
- Variation of the opening height  $h$ :  $h = 5 \text{ m}, h = 10 \text{ m}, h = 15 \text{ m}$ .
- Variation of the opening position  $Z_{open}$ :  $Z_{open} = Z_{min} = -1.5 \text{ m}, Z_{open} = 0 \text{ m}, Z_{open} = 10 \text{ m}$ .



**Figure 1**

For each geometry three different wind directions are considered (Figure 2):

- wind in  $+x$ -direction: opening is located in the windward direction, which leads to tensile stresses at the vertical edges of the opening.
- wind in  $-x$ -direction: opening is located opposite to the windward direction, which leads to compressive forces at the vertical edges of the opening.
- wind in  $+y$ -direction: crosswind, which leads to shear around the opening.



**Figure 2**

To figure out the influence of a temperature difference  $\Delta T_M$  two different values (50 K and 100 K) are considered.

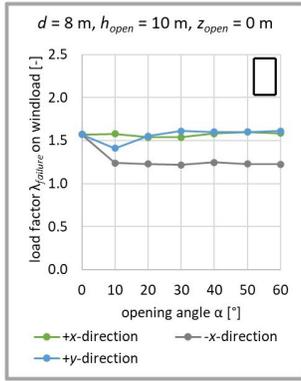


Figure 3

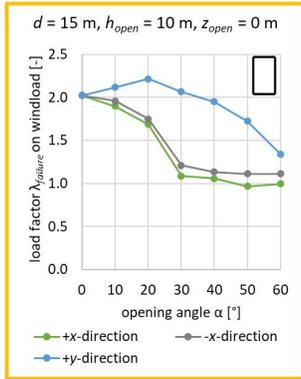


Figure 4

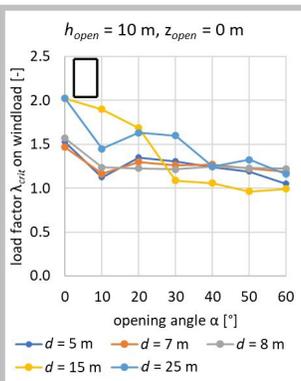


Figure 5

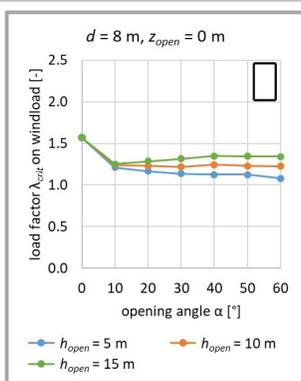


Figure 6

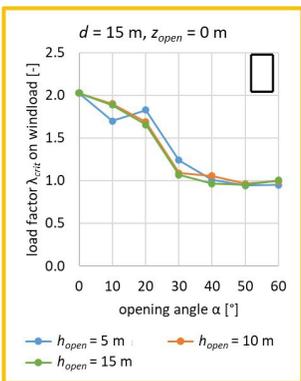


Figure 7

Because of CICIND Model Code [1] not giving any advice where exactly to place the additional reinforcement around the opening, three different variations of the placement of the additional reinforcement are examined (wide *w*, medium *m*, tight *t*). The width of the area where the additional vertical reinforcement is placed, varies between 0.1 and 0.25 times the opening width  $b_{open}$ . The additional horizontal reinforcement above and below the opening is placed in an area with a height of the half opening width  $b_{open}$ . For the wide *w* variation, the full additional horizontal reinforcement is placed equidistant over this height. For the medium *m* and tight *t* variation more and even more of the additional horizontal reinforcement is placed closer the opening.

For all those parameter combinations a FE calculation of a shell model with nonlinear material properties is performed. The reinforcement is chosen according to CICIND Model Code [1] for  $G + 1.5 W$  resp.  $G + \Delta T_M + 1.5 \cdot W$ . The load is added stepwise until a failure occurs.

### 3. Results of Nonlinear FE-Calculation for Chimneys with Openings

#### 3.1 Influence of different wind directions

In case of small diameters, with beam-like overall structural behaviour of the chimney ( $h/d > 17$ ) (Figure 3), wind direction from  $-x$ -direction, i. e. from opposite direction to the opening, is most critical for the structural bearing capacity in the vicinity of the opening. The influence is comparable for all opening angles  $\alpha$ . Wilson [4] and Kilic [5] revealed the same wind direction to be decisive. Thus those results can be confirmed.

In case of large diameters, with shell-like overall structural behaviour ( $h/d \leq 17$ ) (Figure 4), wind direction from  $+x$ -direction and  $+y$ -direction is most critical for the structural bearing capacity.

For each diameter and each opening angle the wind direction with the minimal value for the load factor  $\lambda_{failure}$  can be seen as the critical wind direction. The load factor of this wind direction will be described as critical load factor  $\lambda_{crit}$  in the following.

#### 3.2 Influence of the chimney diameter *d* (Figure 5)

In case of small diameters *d* with beam-like overall structural behaviour of the chimney ( $h/d > 17$ ), the influence of the chimney diameter is comparable for all opening angles  $\alpha$ . The critical load factor is reached when the wind in  $-x$ -direction causes compressive failure at the edges of the opening.

In case of large diameter *d* with shell-like overall structural behaviour ( $h/d \leq 17$ ), the load factor  $\lambda_{crit}$  and thus the ultimate limit decreases with increasing opening angle  $\alpha$ . But it must be mentioned that for chimneys with large diameter *d* the absolute width  $b_{open}$  is much larger than for chimneys with smaller diameter and thus might be out of the range of practical application. For large diameters *d* the max. compressive force is not situated opposite to the windward meridian but on the side flanks of the chimney, so for these diameters wind from  $-x$ -direction is not decisive. The critical load factor is for almost all considered opening angles  $\alpha$  reached when a failure in the shell occurs, not directly at the opening.

#### 3.3 Influence of opening heights *h<sub>open</sub>*

In case of small diameters *d* with beam-like overall structural behaviour of the chimney ( $h/d > 17$ ) (Figure 6), the load factor  $\lambda$  and thus the ultimate limit decreases with decreasing opening height  $h_{open}$ . Then openings with smaller heights are clearly accompanied by a decrease of the critical load-factor  $\lambda_{crit}$  because of larger stress concentrations in the corners. This result confirms the findings of van Koten [6].

This behaviour cannot be observed in case of large diameters with shell-like overall structural behaviour ( $h/d \leq 17$ ) (Figure 7), where the load factor  $\lambda_{crit}$  and thus the ultimate limit is more dependent on the size of the opening angle  $\alpha$  than on the opening height  $h_{open}$ .

#### 3.4 Influence of the opening position *Z<sub>open</sub>*

The influence of the opening position  $Z_{open}$  is minor (Figure 8). Only for the investigated shell-like chimney with  $d = 15$  m the upper position  $Z_{open} = 10$  m results in different behaviour.

### 3.5 Influence of different reinforcement distributions in the vicinity of the opening

For beam- and shell-like chimneys the critical load factor  $\lambda_{crit}$  on wind load is approximately the same for all considered reinforcement distributions (Figure 9). This results in the recommendation, to distribute the reinforcement not depending on the opening width, but depending on practical restrictions for placing the single reinforcing bars, like sufficient spacing, overlapping etc.

### 3.6 Influence of thermal difference $\Delta T_M$

As expected, the additional consideration of thermal action will further decrease the load factor  $\lambda$  and thus the ultimate limit (Figure 10 and 11). The larger the opening angle  $\alpha$  is, the larger is the reduction of the critical load factor  $\lambda_{crit}$  on wind load caused by thermal stresses  $\Delta T_M$  compared to the values without considering temperature differences. Thus, thermal action will affect the structural integrity of chimneys with openings, which cannot be covered by the basic reinforcement due to Model Code [1]. Significant thermal difference  $D T_M$  needs to be considered in the numerical analyses. This results in the recommendation, to investigate the vicinity of openings via shell analysis, even of the chimney geometry is beam-like ( $h/d > 17$ ).

## 4. Outlook

To make nonlinear analyses tools more stable is still a matter of fundamental research. In order to eliminate or at least to quantify the effect of numerical deficiencies, which might still be inherent in the SOFiSTiK-software [7], either in the finite elements or in the nonlinear tools, it is inevitable to validate the results with another software system. Unfortunately, this was not possible within the scope of the present research project. But of course, all results of the presented nonlinear investigations must be looked upon as merely tending to the real solution, even so they will never represent it exactly. Thus, at the end, by using nonlinear analysis methods in the present research project, the effects of different variants of opening sizes and locations can only be looked upon as qualitatively correct, but not quantitatively exact.

The consequences of the current results for practical application can be implemented either in an update of the Model Code [1] or in its Commentaries [2]. The authors of this report recommend that a consideration of the thermal differences for the calculation of the additional reinforcement around the opening should be included in Model Code [1].

## 5. Acknowledgements

The paper has presented results of the research project “Validation of Current Design Concept for Concrete Chimneys near Openings via Nonlinear Shell Analysis”, financed by CICIND [3]. The support by CICIND is gratefully acknowledged.

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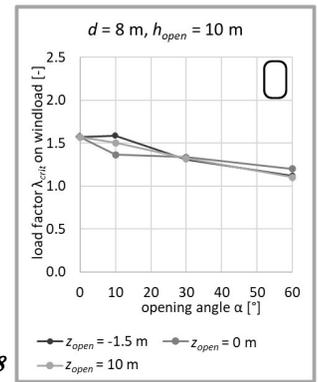


Figure 8

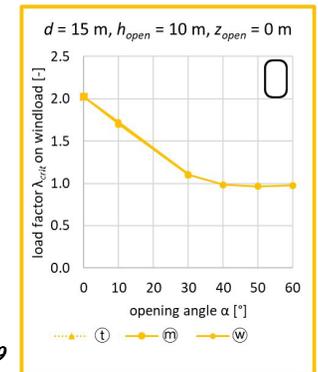


Figure 9

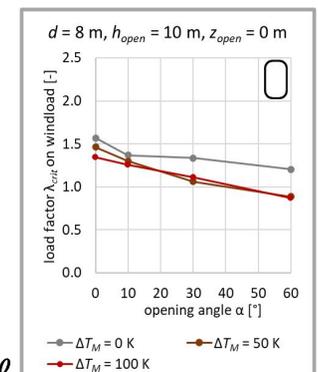


Figure 10

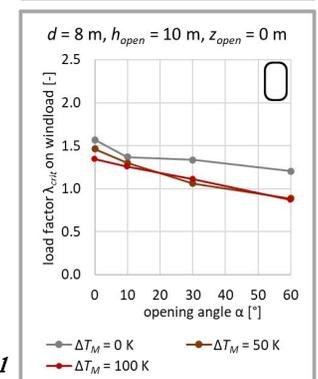


Figure 11



**“Unai Rodríguez,**

Mr. Rodríguez is a Spanish born Technical Industrial Engineer who in 2010 co-founded Accesus Plataformas Suspendidas, S.L. with two more coworkers. Accesus offers standard products and special solutions related to suspended platforms at heights and difficult access places, specially in industry all over the world. Prior to this he worked for around 10 years in technical departments as a manager in companies of the sector. He is married and has two young children

# High Performance Equipment for Working-at-Height

*Ramon Esteve, Unai Rodriguez  
Accesus*



**Presentation:**

- Accesus is the combination of a big team of professionals dedicated to the design, manufacture and sale of suspended platforms, special scaffolding, safe access systems for work at height and special access for people.
- Born in 2009, Accesus team has more than 10 years of experience offering quality, design and safe solutions.
- We are specialized in works at height and difficult access, so what defines us most are rigorousness in the manufacture and approval of our products and protocols, PPEs.

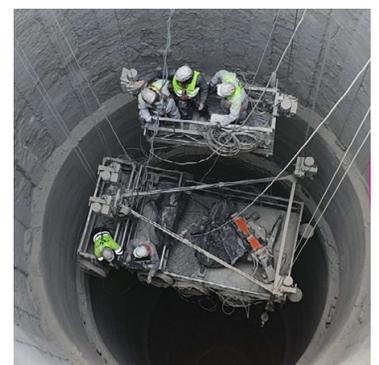


**Project:**

**High Performance Equipment For Working-at-Height**

Client: ENDESA  
Location: Compostilla Thermal Power Plant (Spain)

The client asks us for a solution to place a demolition robot inside a 120m high chimney. The customer requires a platform to place a demolition robot inside the chimney for the purpose of removing the asbestos coating. The customer also needs an auxiliary hanging platform so that operators can access the main platform. The two machines will have to have the option of moving around the perimeter of the interior of the chimney to access all sides.



The concrete structure of the remaining chimney will be demolished by controlled blasting.

In the Accesus technical office, we work to develop a solution to the client's requirements and all the necessary elements are designed to carry out the work required by the client.

## Equipment Characteristics

The proposed solution is a platform with equipment to place the demolition robot and another for 2 operators that will be adjustable to fit the diameter of the inside of the chimney. It will be suspended from a metal rail installed at the top which allows the equipment to rotate around the interior perimeter of the chimney.



Ascent and descent of the main platform

Rotation of the main platform

Suspension structure that meets the specifications described in the UNE-EN1808 standard and the European Directive 2006/42/CE.

## Benefits

- Access to the entire interior work surface
- Electrical horizontal and vertical movements
- Adaptable to multiple types and sizes
- Unlimited height
- Dismountable equipment for access to the interior of installations.
- Total security and certifications
- Cables collected to prevent damage from falling objects during demolition.



The platform, control cabinet and suspension rail are manufactured. Tests are carried out in the workshop and finally the material is collected and shipped.

The planning of the assembly is prepared and the movement of personnel to the work is carried out.

These special pieces of equipment require a complicated assembly on site, both to assemble the davit on the upper part and to place the platform inside. A piece of equipment is placed in the upper part exclusively to enable lifting all the material from the davit.



Accesus offers support for technical assistance and maintenance of its equipment during the work.

## Documentation

Declaration of Conformity CE

Technical sheets and operating manuals

Assembly check and load test certificates

Training certificates

The objective is to provide the client with equipment and a service that facilitates access and work in places at height.





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**Michal Kociniak**

Michal Kociniak is the Chief Engineer of the BEROA Division for Tall Structures in Germany, part of DOMINION Industry. Before, he had his own engineering company in Krakow, Poland. He obtained his academic degree at the Krakow University of Technology in 2000. He has almost 20 years of experience working in chimneys, cooling towers and other industrial structures.

# Gas turbine stacks - specifics, design and recommendations

*Michal Kociniak<sup>1</sup>*

<sup>1</sup>*DOMINION Deutschland GmbH, DOMINION Steelcon*

**Abstract**

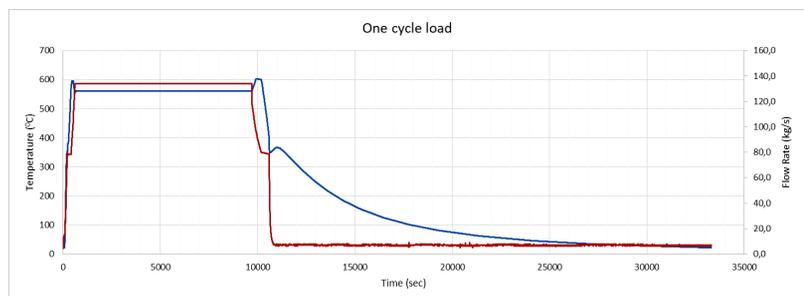
Recent years have shown a development in the gas-fueled power generation industry. It is connected with construction of many gas units equipped with steel chimneys as the exhaust gas discharge system. Such chimneys are characterized by carrying away flue gases with high temperatures reached after quick starts. This article presents the problems associated with the design approach for this type of chimney.

**1. Characteristic of stack for gas turbines**

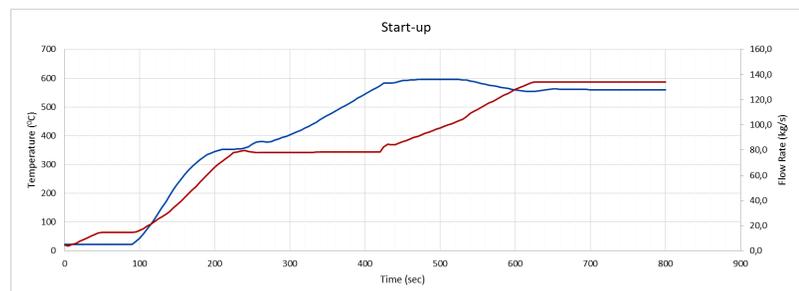
The chimneys of such gas turbines are characterized by an electrical output ranging from 25 to 200 MW. Typically, these are chimneys with liners of 2.0 to 6.0 m in diameter. The height of the chimneys, depending on the unit, can be 20 m but can also reach 60 m and more. In many cases these chimneys are equipped with silencers. The silencers are installed inside the chimney (in some cases on two elevations). They can also be located just in front of the chimney inlet.

**2. Operating conditions**

Gas turbine chimneys, unlike typical coal flue stacks, must discharge high temperature flue gases. Typically, the flue gas temperature reaches a range of 500-600 degrees Celsius but can also reach 750 degrees Celsius. A characteristic feature of this type of chimney is its fast start-up. The start-up time, from shutdown to full operation, takes a few minutes. Typically, it is between 8 and 12 minutes. There are also units for which the start-up is less than 5 minutes. Figure 1 shows a typical cycle for one load (start-up, continuous operation and shutdown). Figure 2 shows the temperature distribution during start-up and flow until steady-state conditions are reached.



**Figure 1: One cycle load of gas turbine stack**



**Figure 2: Typical start-up curve**

### 3. Standard design approach

For typical chimneys, the standard design approach includes checking for displacement, bearing capacity and global as well as local stability. Checking is carried out for a steady state temperature, usually the maximum operating temperature. The stress state is checked, but rarely the strain state, as typically the standard conditions involve elastic working, i.e., before reaching yield point. This approach is not sufficient for hot chimneys, for which temperature is the main load. In addition, the temperature change is rapid which has a significant influence on the strain and stress distribution.

### 4. Transient calculations

The computational approach of gas turbine stacks requires calculations in the time domain, both for temperature calculations and for mechanical calculations. Calculations should be performed for complete load cycles considering a minimum of two cycles. For successive time steps the temperature fields, which represent the heat flow status of the system, have to be calculated. Figure 3 presents example calculation of temperature fields. Calculations of this type can be complex. CFD calculations must often be taken into account as a basis for determining the temperature fields in the individual components of the chimney (gas duct, strengthening and support zones, ventilated space or external shaft of the chimney). Calculations include consideration of all three types of heat flow. Conduction flow takes into account the transport of energy through solid bodies (steel elements, thermal insulation). Convection is considered when calculating the heat transfer coefficients from hot flue gases on the wall of the gas duct, or the outflow of the liquid outside the chimney to the environment. Convective heat transfer also occurs when heat is distributed in closed air spaces or in a ventilated space. Radiative heat transfer must also be considered in the calculations as it can represent a significant percentage of the heat transferred from the hot elements to the surfaces of the elements separated by air spaces. Figure 4 shows schematically all three types of flow and where they can occur.

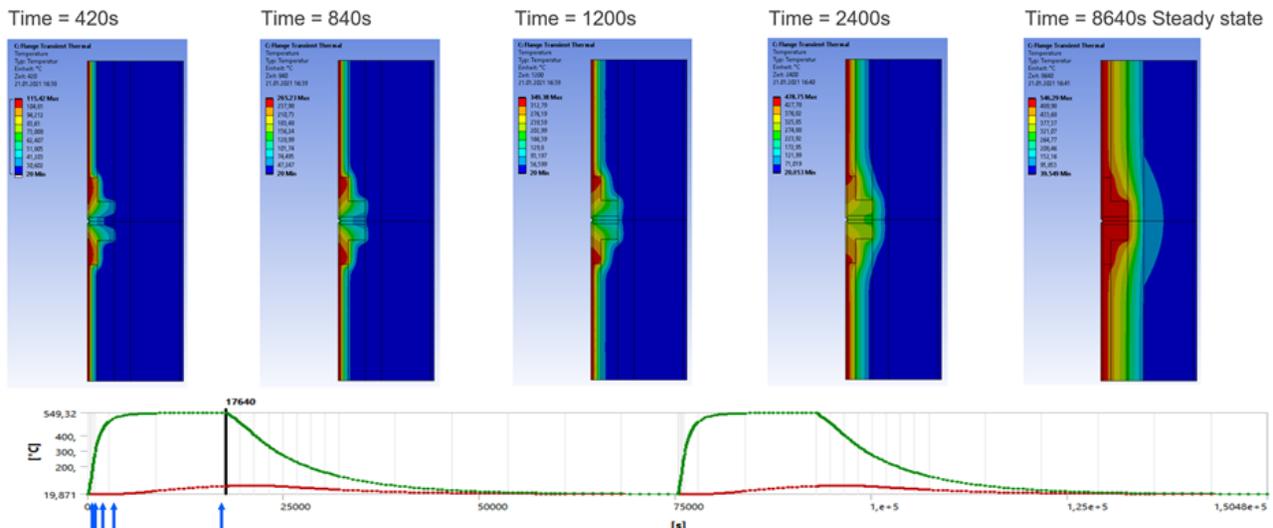


Figure 3: Calculation of temperature field for different time steps

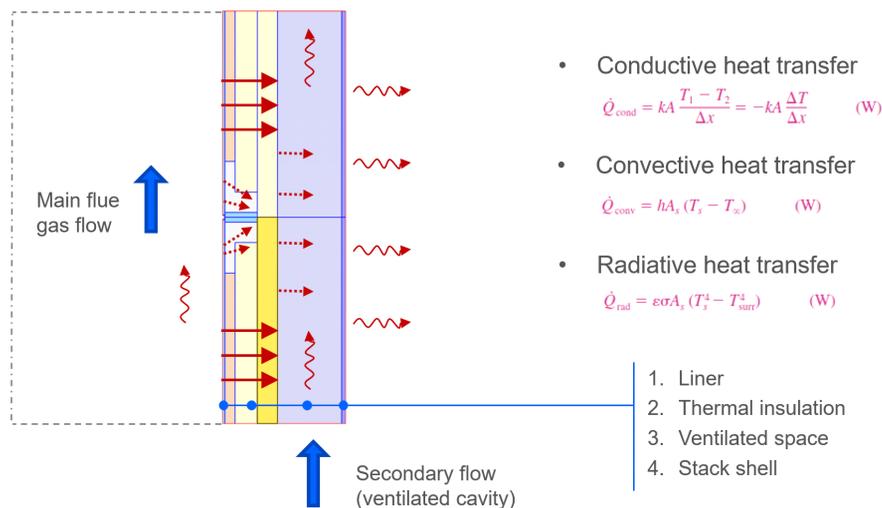


Figure 4: Conductive, convective and radiative heat transfer in steel gas turbine stacks (schematic)

The temperature fields for the individual time steps should be exported to the mechanical model and on this basis the state of deformations and stresses changing during the start-up until stationary conditions are reached should be calculated.

### 5. Calculation basis

In order to take into account all possible system behavior, the following parameters have to be taken into account for the flow calculation (CFD calculation) and temperature distribution:

- Model of flue gas:
  - Density: Ideal Gas
  - Specific Heat: Function of temperature
  - Thermal Conductivity: Function of temperature
  - Viscosity: Function of temperature
- Geometry: 3D or in some cases simplified 2D
- Unsteady flow conditions (mass flow and temperature depends on time)
- Compressible flow
- Turbulent flow to cover pressure and velocity distribution related to geometry of the system
- Heat Transfer in solids
- Shell Conduction model for liner, insulation and outer shell
- Gravity activated to account for convective heat transfer
- Radiative heat transfer

Figure 5 shows results of 3D CFD calculations (model, flow and velocity distribution, temperature fields).

Parameters to be considered in the numerical model for mechanical (structural) calculations:

- nonlinear effects (Plastic deformations when stress reaches yield point)
- Thermal expansion and strains
- Time step analysis
- Large deformations analysis to account for excessive plastic strains
- Material properties – temperature dependent
- Multi-load cycle analysis
- 3D solid or shell model

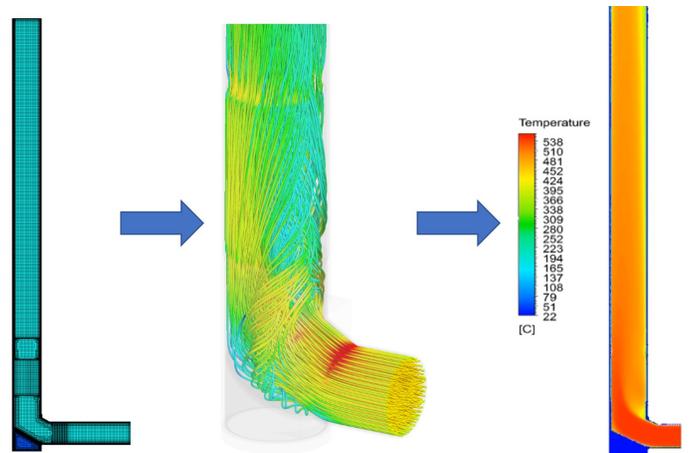


Figure 5: CFD model, flow and velocity distribution, temperature fields

The calculations require a non-linear approach, which is characterized by non-linearity of the material as well as non-linearity of the supporting conditions. The calculations take into account the full material characteristics of the steel, i.e. the entire stress-strain relationship range. As the thermal stresses reach the yield point of the steel, it is necessary to check the plastic deformation, which determines the behavior of the system.

Calculations must consider the temperature-dependent characteristics of the material. Figure 6 shows the steel parameters for different temperature values.

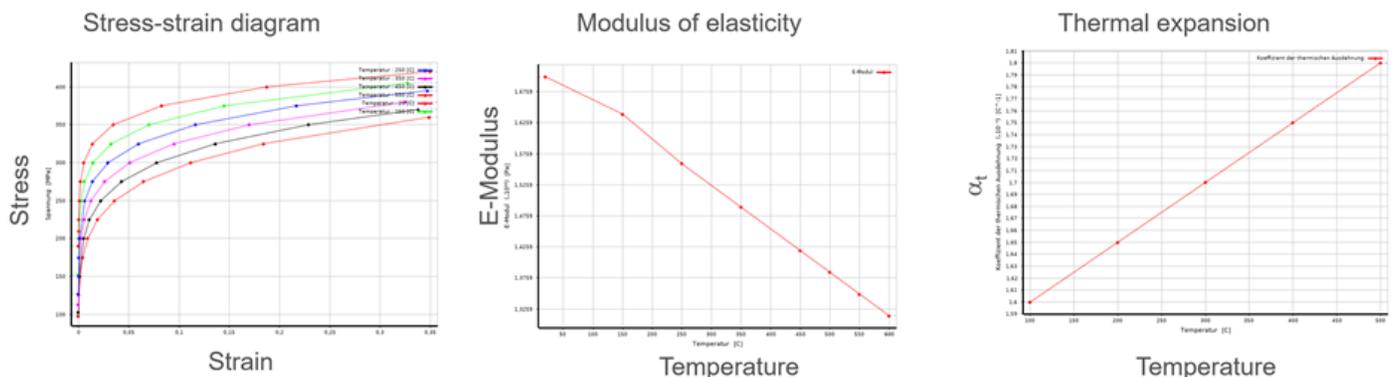
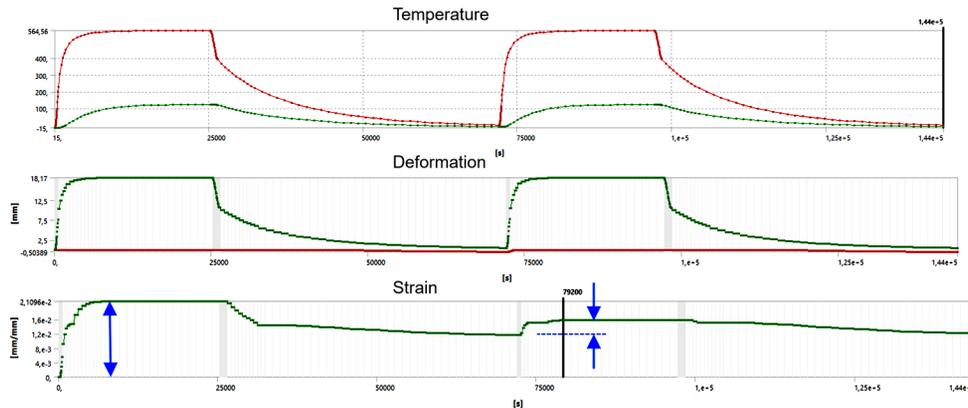


Figure 6: Temperature dependent parameters of steel material (strain-stress relationship, E-modulus and thermal expansion coefficient).

Control of the development of stresses and strains requires calculations for load cycles. Since after the first load cycle, due to thermal stresses, the yield point is reached in some areas of the structure, the system is initially constrained. The strains and stresses necessary to check the service life of the structure must be measured in relation to this first cycle and not to zero conditions. Figure 7 shows the development of temperature, deformation, and strain for two successive cycles of operation.



**Figure 7: Temperature dependent parameters of steel material (strain-stress relationship, E-modulus and thermal expansion coefficient).**

The level of deformation of the steel, in particular plastic deformation, needs to be checked. The yield point of the steel is reached in the critical regions and therefore checking only the stress level is not meaningful to verify the safety conditions.

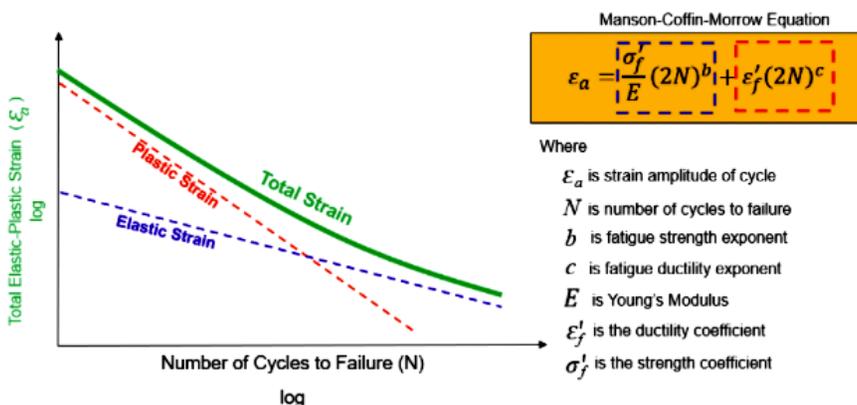
The above requirements impose the use of specialized software. Manual calculations are not an option. Most typical structural calculation programs do not have the required capability to take into account multilevel non-linearities. Computer systems that offer the possibility of such calculations but also guarantee the accuracy of the results are ANSYS Workbench, ABAQUS, Comsol.

### 6. Calculation of lifetime

The aforementioned reaching of yield point and the occurrence of plastic deformation occurs at each load cycle. Due to the multiple starts and stops of the turbine, the system is subjected to many load cycles during its lifetime. As mentioned above, the conditions for checking the stress level and the strain value alone do not give any information on the expected lifetime of the stack. This makes it necessary to test the structure for multiple alternating loads and to check the fatigue conditions. Only the fatigue check will give an answer to the service life of the system. Low cycle fatigue (LCF) usually refers to situations where the stress is high enough for plastic deformation to occur, the accounting of the loading in terms of stress is less useful and the strain in the material offers a simpler and more accurate description. This type of fatigue is normally experienced by components which undergo elastic-plastic or plastic deformation. The reason why strain life is more suitable for low cycle fatigue is that the strains allow the elastic and plastic components to be distinguished from each other, whereas the stress is way less sensitive to the plastic component in the case of high amplitude. The arbitrary classification between high cycle fatigue (HCF) and low cycle fatigue is roughly 10,000 cycles; however, the exact number of cycles really depends on the properties of the metal.

In the case of high cycle fatigue control under repeatedly varying loads, the range of stress variation is small, while the number of load cycles is large. Examples of such structures are e.g. crane beams or structures subjected to mechanical dynamic loads. In the case of the discussed gas ducts, thermal loads enforce plastic deformations and fatigue control requires the investigation of the range of strain variation. This approach is known as Life Strain Calculation (EN Method). As mentioned, stresses are large enough for plastic deformation to occur. Strain Life differs from other approaches to fatigue because it considers both the elastic and plastic deformation of a material. Some approaches, like Stress Life (SN Method), are only suitable when the stresses and strains remain in the elastic region of a material.

There are several methods for checking the strain dependence of the number of load cycles and one of them is the approach proposed by Coffin and Manson in the 1950s. Figure 8 shows the relationship considering elastic and plastic strains and their sum, total strain.



**Figure 8: Manson-Coffin-Morrow curve**

Figure 9 presents EN-curve for specific materials and different temperatures. As can be seen occurrence of larger plastic strain ranges results in drastic drop of allowable load cycles and reduction of a lifetime.

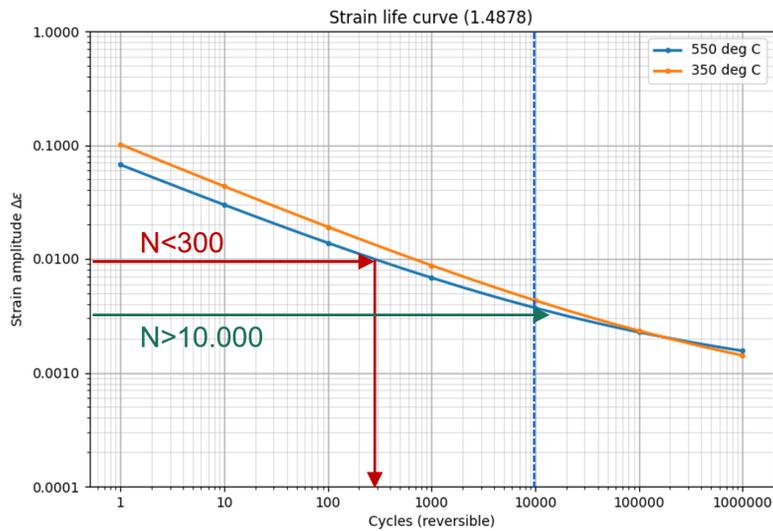


Figure 9: EN-curve and ranges of strain amplitude and corresponding number of load cycles

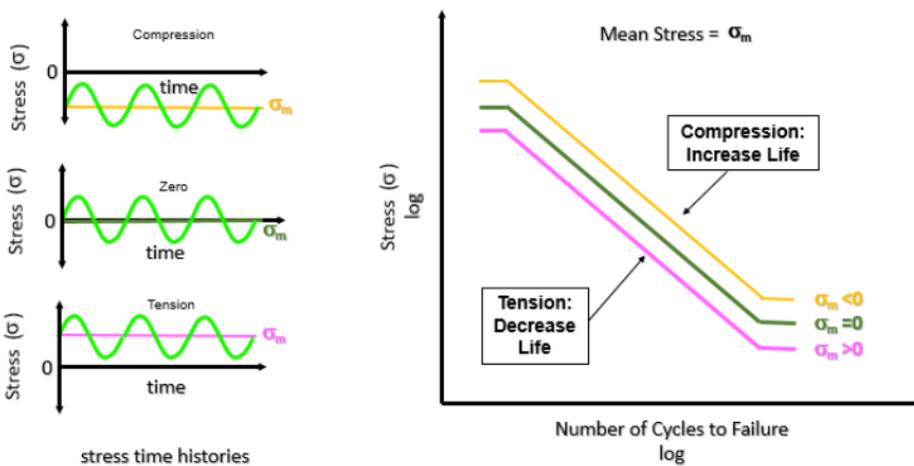


Figure 10: Mean stress correction

In calculating low cycle fatigue, stress levels must be considered in addition to the nominal curves. Typical curves are constructed for fully reversible loads i.e., maximum tension and compression (Figure 10). In actual construction, some areas are in tension only or compression only. It may happen that the range of change of strain does not change sign but goes from high compression to lower compression, for example. This should be taken into account in the calculations by applying a Mean Stress Correction. Generally, tensile stresses reduce fatigue life and compressive stresses increase it.

Another parameter to consider is the certainty of survival. Typically, curves are constructed for a survival confidence of 50% until fatigue cracking occurs. This may not be sufficient to ensure safety of the structure and an appropriate adjustment must be made. Again, a higher confidence value means a smaller acceptable range of strain variation. This is illustrated in Figure 11.

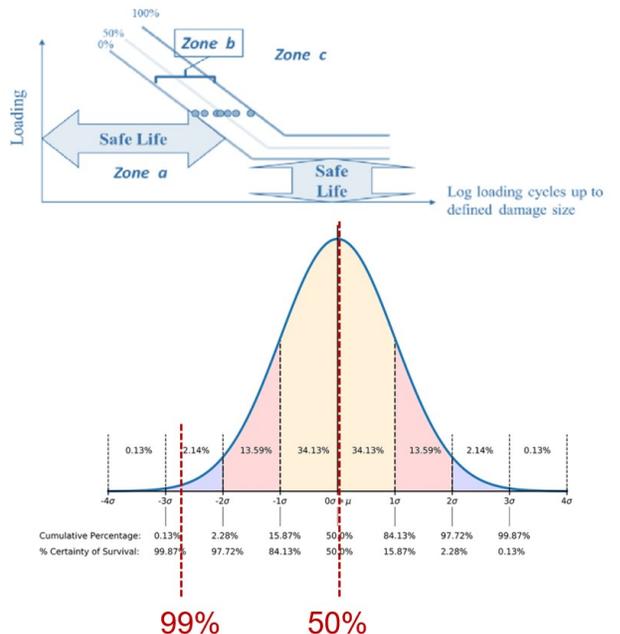


Figure 11: Certainty of survival

### 7. Recommendations

Special care should be taken in areas of liner reinforcements such as stiffening rings and flange connections. Typically these areas will be covered with a thick layer of thermal insulation. However, this is not the approach to ensure that thermal stresses are kept under control in all cases. When the internal surface of the duct is heated quickly, the stiffener ring (or flange) on the outside is cooler, which means that it will not expand as quickly as the duct. This results in a restriction to the thermal deformation and thus the development of thermal stresses and strains, which can cause fatigue cracking. Figure 12 shows a detail of such a joint and the temperature difference inside and outside the flange. One solution may be to use an air void instead of thermal insulation. This has the advantage of taking advantage of the radiation from the hot pipe, which emits heat directly to the flange, thus heating it faster and reducing the temperature difference.

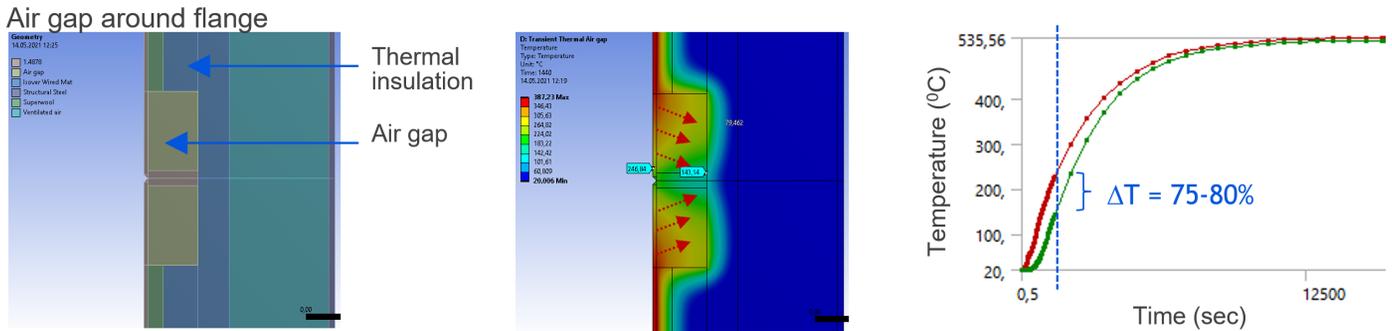


Figure 12: Temperature difference reduction due to additional radiative heat transfer in the area of flange

If parts of the cable remain uninsulated, heat loss and a significant temperature difference may result. This obviously causes a difference in thermal expansion and results in additional deformation restraints. The aim should be that the heat is distributed uniformly in the component and that the whole is as uniformly hot as possible.

Leaving of air closed-in small gaps might influence heat transfer and can lead to additional stresses due to increase in air pressure. Air is a good insulator and restricts heat to flow through such a gap. Figure 13 presents detail of flange welded to the liner by means of fillet welds. This configuration creates small gap where air is closed. Heat can flow through the welds while gap creates a barrier. In addition, pressure increase due to temperature increase of 500 degrees Celsius may reach value of few bars and cause additional stresses in liner and welds. All fittings and reinforcements shall be welded by means of full penetration welds.

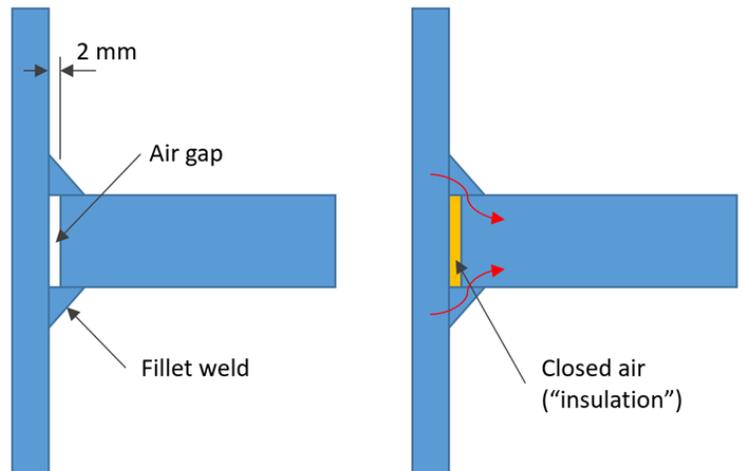


Figure 13: Closed-in air gap area of stiffening ring

### 8. Conclusions

- Transient thermo-mechanical calculations are required to check design lifetime of gas turbine stacks and their liners.
- Liners are subjected to Low Cycle Fatigue (with no of cycles far below 10.000). Fatigue is main check criterion for evaluation of safety.
- Main design parameter for a prediction of a lifetime is number of start/stop cycles. It is important to get the information about assumed operation of the unit including frequency of starts and the duration of operation.
- Temperature should be kept in the structure (no excessive cooling should take place)
- Special care must be taken by design of thermal insulation. Adding thermal insulation might not always solve problems with temperature difference between adjustment components.
- Proper welds are crucial for a design lifetime. Fillet and intermittent welds shall be avoided. Full penetration welds are recommended as providing more reliability.
- Quality assurance is an important factor to ensure correct execution of components and welds and to ensure desired lifetime of stack.



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**James M. Daniel**

Jim is a Mechanical Engineer with a BSME from the University of Massachusetts in Amherst and an MSME from Worcester Polytechnic Institute. James joined Alden Research Laboratory in 2002 and has almost 20 years of experience consulting in the electric power generating industry and providing solutions to flow related problems. Jim’s particular areas of expertise are designing liquid collection systems for wet stacks and designing flow control devices for electrostatic precipitators

# Recent Advances in the Development of Liner Technologies for High Speed Wet Stack Operation

*James M. Daniel, Senior Engineer,  
Alden Research Laboratory, Holden, MA, USA*

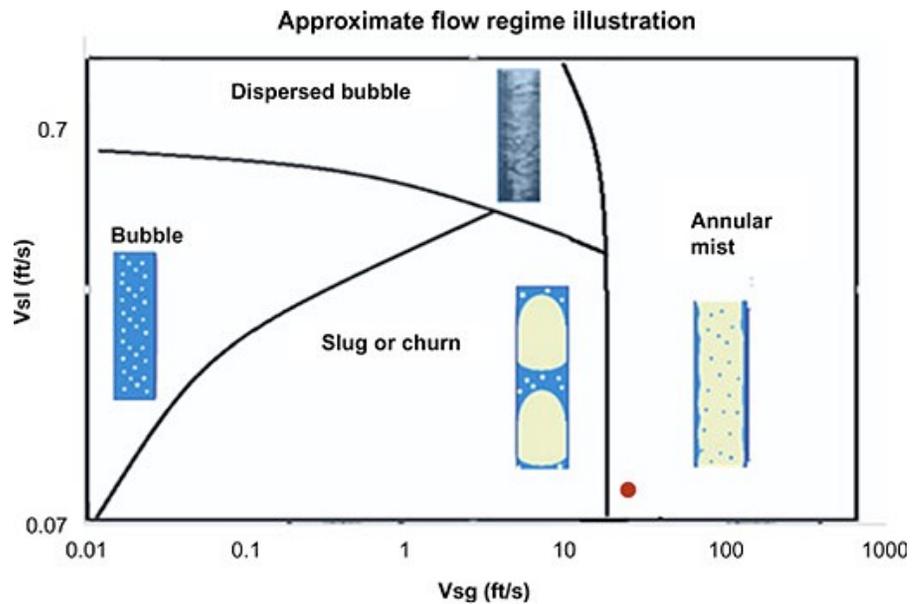
## 1. Introduction

The recommended area-averaged stack liner velocities for wet operation are provided in the Revised EPRI Wet Stack Design Guide (2012) [1] for the typical wet stack liner materials (Brick, Alloy, FRP, Borosilicate Block, & Coatings). Recent technological developments have increased the operating range of the borosilicate glass blocks from 60 ft/s (18.3 m/s) up to 70 ft/s (21.3 m/s).

## 2. Background

A wet stack is a chimney, a stack, or flue that exhausts saturated flue gas downstream from a wet scrubbing process such as a wet flue gas desulfurization (FGD) system. All recently designed and constructed wet FGD systems have installed wet stacks.

Wet stacks operate in a 2-phase gas and liquid flow regime and in particular are in the Annular Mist regime as shown in Figure 2-1 [2]. The Annular Mist regime is categorized with an annular film of liquid on the liner wall with flue gas as the central core flow. Entrained liquid droplets of varying size are interspersed throughout the gas core flow.



*Figure 2-1: 2-Phase Gas & Liquid Flow Regimes*

Figure 2-2 shows the corresponding liquid film flow patterns with vertically upwards gas flow. The general flow patterns hold true for most liner materials; however, the corresponding velocities for each flow pattern are material specific.

- At gas velocities below 50 ft/s (15.2 m/s), the liquid flows smoothly downward with no re-entrainment.
- Small waves begin to form on the surface of the liquid as the gas velocity increases to 55 to 65 ft/s (16.7 m/s to 19.8 m/s). The thickness of the liquid film increases and some re-entrainment can be seen.

- A material specific flow reversal transition occurs somewhere in the range between 70 and 85 ft/s (21.3 to 25.9 m/s). During this transition, the liquid film thickness increases, large waves are evident on the liquid surface, and re-entrainment is prevalent. This flow regime should be avoided for wet stack operation as liquid collection is extremely difficult and re-entrainment is high.
- At gas velocities above 90 ft/s (27.4 m/s) the liquid flows vertically upwards. The thickness of the liquid film decreases, small waves are evident on the surface of the liquid and re-entrainment is low. Alden has designed special liquid collection devices to capture liquid at these elevated velocities; however, liquid collection at these velocities is still quite challenging.

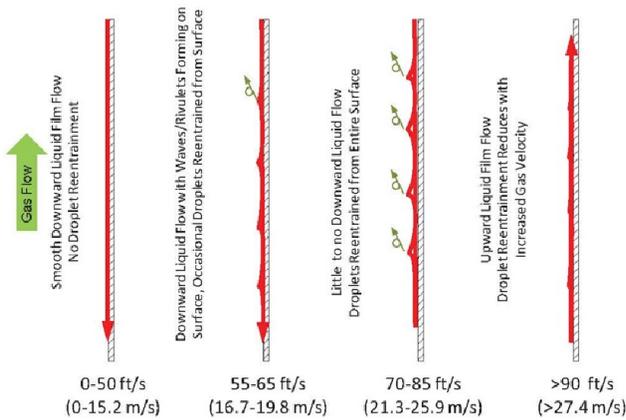


Figure 2-2: Vertical Liquid Film Flow Patterns

Alden designed the EPRI Vertical Liquid Re-Entrainment Facility, shown in Figure 2-3, which was used to develop the recommended operating velocities for the various liner materials. The test facility represents a thin vertical slice of a liner approximately 1.5 feet wide (0.46 m) and has been simplified to simulate the liner as a flat plate instead of using a curved section. It was designed to simulate the turbulent boundary layer in the upper liner where the gas flow profile is well developed.



Figure 2-3: Alden's EPRI/CICIND Vertical Liquid Re-Entrainment Test Facility

For alloy liners, the horizontal weld beads between sections are usually the main limiting factor. Figure 2-4 details the liquid film behavior at different liner velocities for an alloy material. At lower velocities below 50 ft/s (15.2 m/s) the liquid can drain freely across the weld beads. As the velocity is increased to 55 to 60 ft/s (16.7 to 18.3 m/s) the liquid begins to hang up above the weld bead and some entrainment occurs. At gas velocities

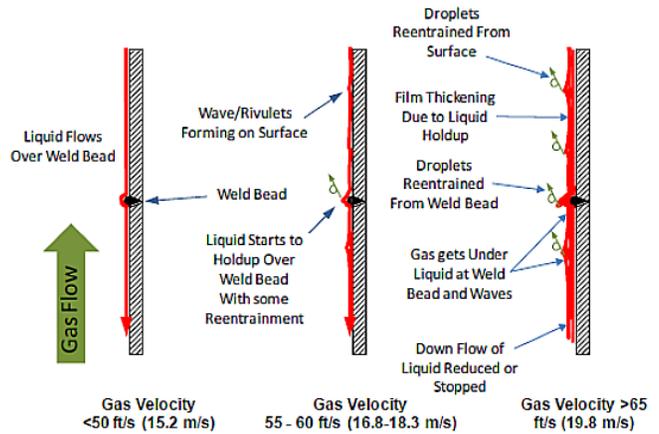


Figure 2-4: Liquid Film Flow Over 1/8" (3 mm) Weld Beads

above 65 ft/s (19.8 m/s) the liquid film layer thickness increases and re-entrainment is prevalent.

For FRP (Fiber Reinforced Plastic) liners, the can-to-can connections are the main limiting factor. As shown in Figure 2-5, the taper should be 1:6 minimum but 1:10 is preferred. At lower gas velocities the liquid film stays attached to the liner and can flow freely across the tapered joint at the can-to-can connections. As the gas velocity increases the liquid film layer thickness increases such that the gas can get under the liquid film and re-entrain it from the surface.

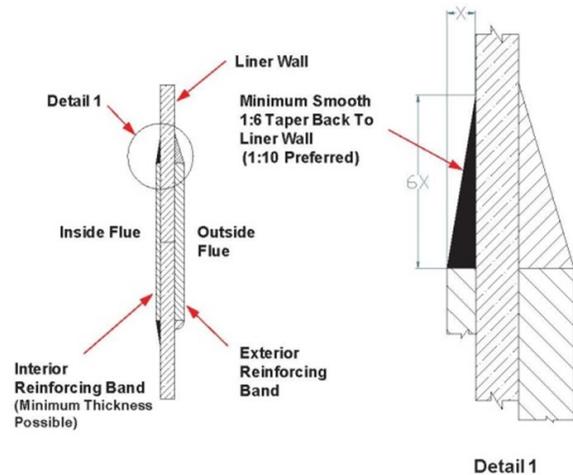


Figure 2-5: FRP Liner Can to Can Joints

For borosilicate glass block liners the horizontal mastic membrane joints are typically the main limiting factor. Liquid drains freely across the surface of the borosilicate glass blocks at most velocities; however, as the velocity increases liquid bars begin to form at the horizontal joints. Liquid can still drain from these bars at velocities up to 60 ft/s with limited re-entrainment. As the velocity increases even higher the re-entrainment becomes problematic.

Table 2-1 [1] lists the recommended maximum area-averaged liner velocities for the various liner materials. The objectives during liner development are to achieve the highest gas velocity without liquid re-entrainment or with minimal re-entrainment while allowing liquid down-flow on the liner surface. There is a note for liner coatings specifying that each coating material should be individually evaluated to determine its recommended limit; however, this recommendation should be applied to the other materials as well since there can be material variability from different manufacturers.

**Table 2-1: Recommended Area-Averaged Stack Liner**

LINER MATERIAL	Liner Velocity (ft/s)	Liner Velocity (m/s)
<b>Acid Brick</b> Radial tolerance of construction is 1/8" (3mm)	45	13.7
<b>Alloy</b> Weld bead height <= 1/8" (3mm)	55	16.8
<b>Fiberglass Reinforced Plastic</b> Minimum 6:1 taper on interior joints	55	16.8
<b>Borosilicate Block</b> Radial tolerance of construction is 1/8" (3mm)	60	18.3
<b>Coatings</b>	55*	16.8*

\*Laboratory testing of coating material is recommended to finalize liner velocity for favorable wet operation

**Velocities for Wet Operation**

Figure 2-6 [3] shows the flow regimes for vertically flowing liquids. For each liner material, the recommended velocities for wet operation are on the upper end of the falling film regime such that they are approaching the flooding regime. The flooding regime is analogous to the flow reversal regime that was previously described. In the flooding regime, the liquid tends to hang up or remain in place. The liquid films flow downward along the liner surface and upward [3] on the surface of the liquid film. Eventually the film thickness increases and leads to re-entrainment. Since the recommendations are already close to flooding regime there is not much room for improvement. For example, borosilicate blocks are recommended to operate at an area-averaged liner gas velocity of 60 ft/s (18.3 m/s) but will begin to enter the flooding regime at approximately 80 ft/s (24.4 m/s).

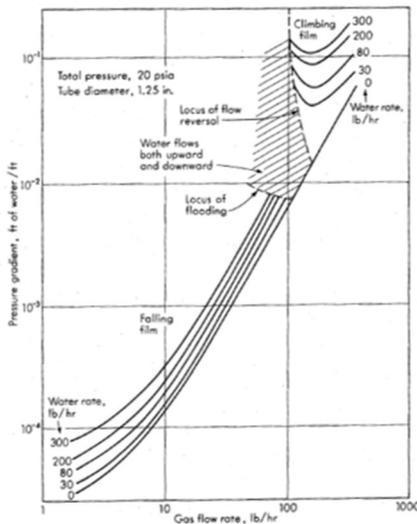


Fig. 11.11 Pressure-drop characteristics near the boundary between countercurrent and cocurrent flow. (Hewitt, Lacey, and Nickolls.19)

**Figure 2-6: Vertical Liquid Flow Regimes**

**3. Recent Developments**

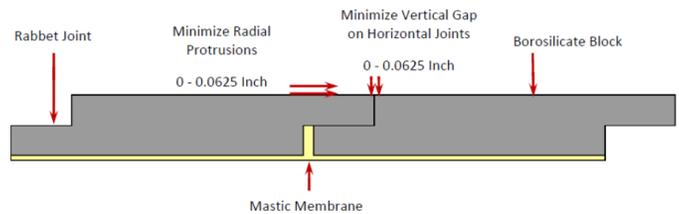
Hadek Protective Systems bv (Hadek) contracted Alden to develop innovative solutions which would enable Hadek’s Pennguard material to function in liners with elevated velocities above the recommendations in the Revised EPRI Wet Stack Design Guide. The standard installation pattern consists of the borosilicate blocks aligned at 90° angles with the short edges on the horizontal joints and with staggered vertical seams. Five different orientations of the Pennguard borosilicate glass blocks were evaluated as shown in Figure 3-1.

The 10° and 20° taper designs did not show any significant improvement versus the standard 90° pattern. The 20° Sawtooth pattern did show improved liquid drainage patterns and was approved for area-averaged stack liner velocities up to 65 ft/s (19.8m/s). Both the 45° taper and the Shiplap designs showed significant improvement and were approved for area-averaged stack liner velocities up to 70 ft/s (21.3 m/s). A schematic drawing of the Shiplap block pattern as shown in Figure 3-2 which shows how the horizontal seams are minimized but still affords protection to the liner.

Shiplap	45° Taper	10° Taper	20° Taper	20° Sawtooth
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**Figure 3-1: Pennguard Test Panels**



**Figure 3-2: Shiplap Block Details**

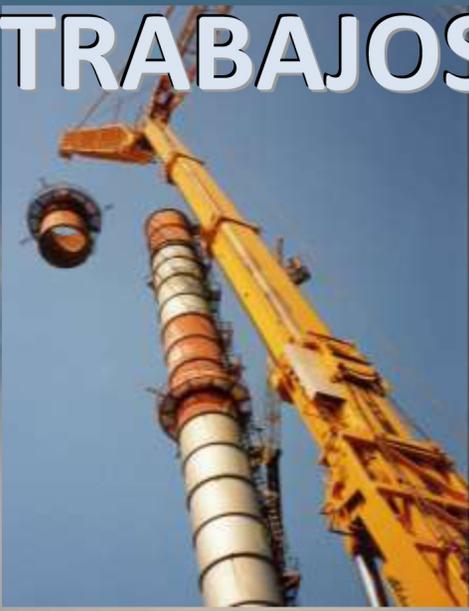
**4. Conclusions**

- The angled block and Shiplap patterns are Hadek patented systems.
- A wet stack model study is still required to design the recommended plant geometry specific liquid collection system.
- When operating an FGD wet stack above 60 ft/s (18.3 m/s) but below 70 ft/s (21.3 m/s) the use of the 45° taper pattern and a high level wet stack model study are both required.
- The recommended velocity limits are based on the area-averaged gas velocity in the respective liner.

**5. Works Cited**

[1] "Revised Wet Stack Design Guide," EPRI/CICIND, 2012.  
 [2] "ScienceDirect.com," [Online]. Available: [https://www.google.com/search?q=2+phase+vertical+flow+regime+chart&rlz=1C1GCEB\\_enUS908US909&tbm=isch&source=iu&ictx=1&fir=6DtZ5Dgl0y9x1M%252Cux4dnT2wofU7xM%252C\\_&vet=1&usg=A14\\_kRefRCYsN9rd5ThsfkWtYRoqzL0jg&sa=X&ved=2ahUKEwiBuL2blprxAhUEnOAKHXUDDo4Q9QF6BA](https://www.google.com/search?q=2+phase+vertical+flow+regime+chart&rlz=1C1GCEB_enUS908US909&tbm=isch&source=iu&ictx=1&fir=6DtZ5Dgl0y9x1M%252Cux4dnT2wofU7xM%252C_&vet=1&usg=A14_kRefRCYsN9rd5ThsfkWtYRoqzL0jg&sa=X&ved=2ahUKEwiBuL2blprxAhUEnOAKHXUDDo4Q9QF6BA).  
 [3] G. L. P. a. N. B. Hewitt, "Transitions in Film Flow in a Vertical Tube," in *Symposium on Two-Phase Flow*, Exeter, 1965.

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### Rick Lohr

long-time CEO and owner of the International Chimney Corporation, Buffalo, USA



### George Gardner,

long-time Chief Engineer of the International Chimney Corporation, Buffalo, USA

# Ten Pounds of Sausage in a Five Pound Sack

*George Gardner P.E. and Rick Lohr*

*ICC-Commonwealth*

## ABSTRACT

A new chimney was required in an operating existing steel plant that originally opened in the 1800s. The thrust of this paper is a description of the requirement, the challenge, the unique solution, the construction, and the ultimate performance of the chimney. The project involved many of our talented personnel, various departments, disciplines, and continually thinking outside of the box.

## CUSTOMER REQUIREMENT

The government insisted upon emitting the gases from the existing power plant in a single source location much higher than the existing stacks. The three stacks were identical in diameter but each one emitted its gas at a different elevation and location, which was much under the new required heights. The customer was under the impression that the restrictions would be relaxed and the major scope of the project would not be necessary. Consequently, they dragged their feet. Unfortunately, early lack of activity drastically reduced the time to get the project done. The completion date if not met was subject to massive fines. Once the customer realized both the fact that they would not be able to receive relaxation of the time requirement and the drastic financial penalty, International was asked for a workable design and construction schedule to achieve the difficult completion date.

## SPECIFIC CHALLENGES

The plant required that one boiler always remain in operation and that the site must remain active. There was continual movement of men, equipment, and material through the construction area. There was little known about actual underground encumbrances. The footprint was small. The site had limited accessibility. The new emission elevation was approximately 175 feet. All liners had to operate independently but had to be in extreme close proximity so that in essence there was one emission point. It was necessary to maintain proper exit velocity for each individual boiler. Many of these requirements were required to emulate one emission location at one velocity so that the unit would act as if all gases were emitted from one single flue location. Hence ten pounds of sausage in a five-pound sack.

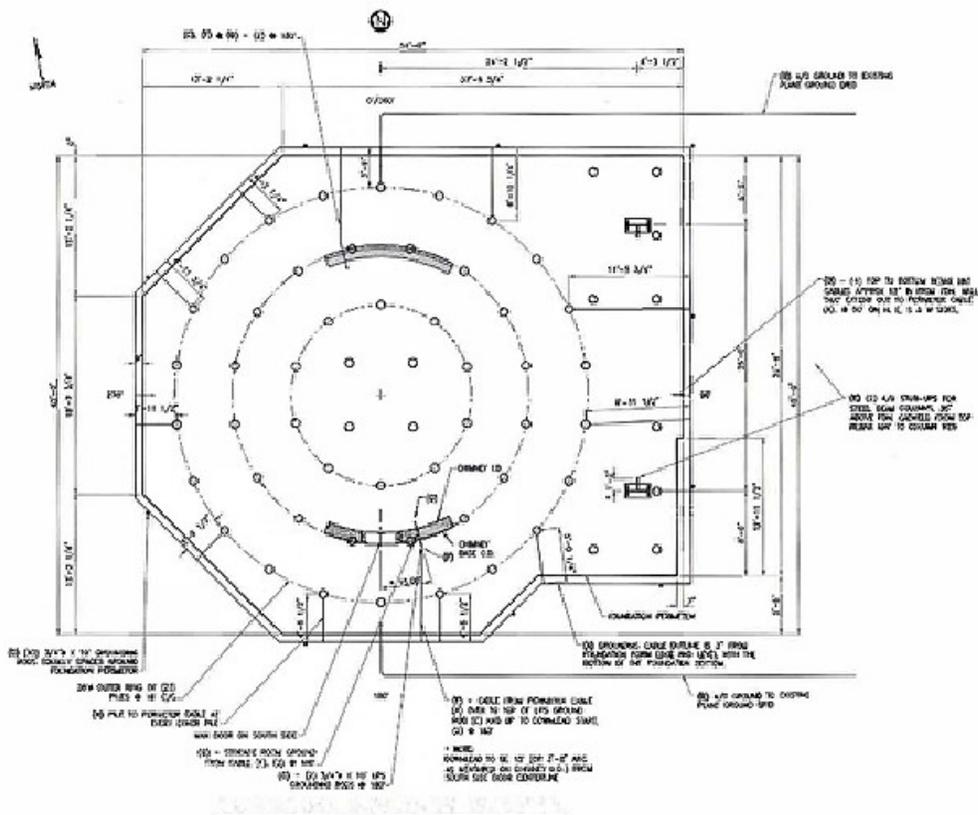
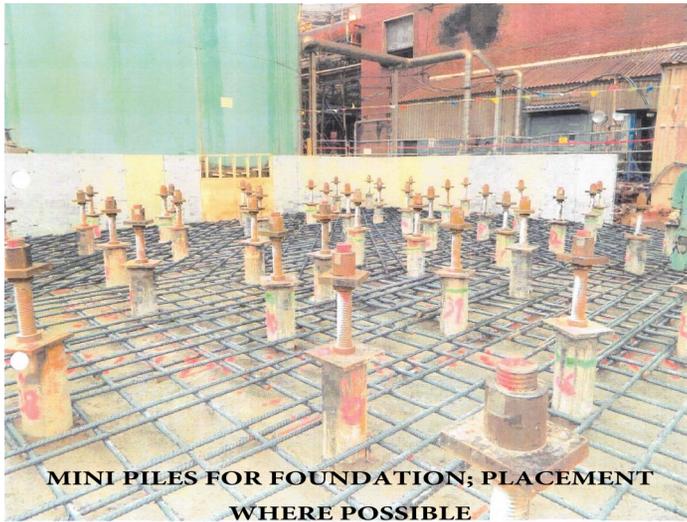
## DEVELOPMENT OF SOLUTION

Originally we approached the idea of a straight, non-tapered, concrete column with a single brick or steel liner. Not good as this would not allow independent boiler operation with a specific exit velocity. Three independent cylindrical liners of brick or steel would also not work due to the necessity of a large diameter wind shield. Accepted design parameters would not allow for a large enough column. A single diameter liner could not be used due to the velocity and independent operation criteria. We settled on a challenge of maintaining independent flues inside a circumference that was slightly larger than the diameter that would normally be used if all gases were joined together. This required a uniquely designed liner system that maintained independence, allowed for expansion and contraction, primarily vertical, while still fitting in the optimum circle. Deciding on the diameter, we then had the challenge of working with the available footprint to meet proper, accepted design foundation requirements. We were able to solve the problem with a unique approach that became extremely challenging but doable.

### EXCAVATION AND FOUNDATION

Our local office worked with the customer and we assigned one of our seasoned professional engineers, Dan Rider P.E., as he had extensive experience with foundations. His experience included both design and installation. It was necessary to learn everything possible about what was under the existing site, as well as what types of foundations existed for some of the old, still operating equipment on the site that might intrude. One example is a large operating cylindrical water tank with undocumented support. We learned enough to be able design the profile and depth of our new foundation, along with what type of support we had to use. An irregular perimeter profile was necessary,

along with extensive mini piles in numbers that allowed for placement adjustment as unknowns were uncovered. We had to use equipment that could be easily brought through the difficult passage to the site. Much of the work was performed on a 24/7 basis in a hurry up and stop mode. There were live, supposedly dead, various feed lines that had to do with the operation of the boiler house that had to be considered. Even with all precautions, we did have some flooding due to the rupture of an ancient, underground water line that was not supposed to be active.



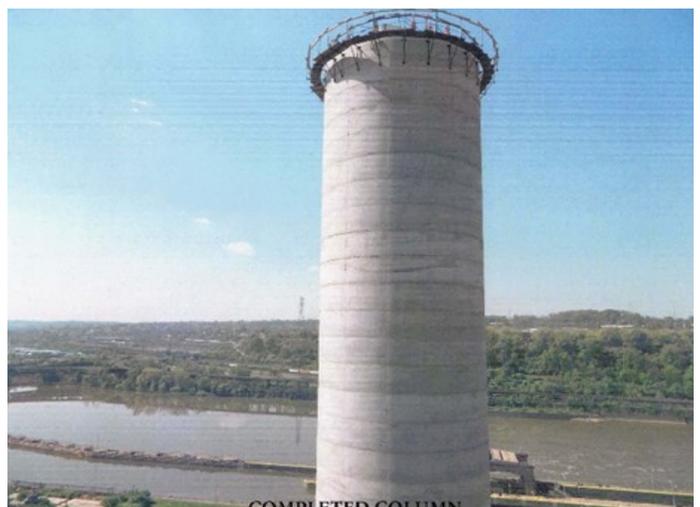
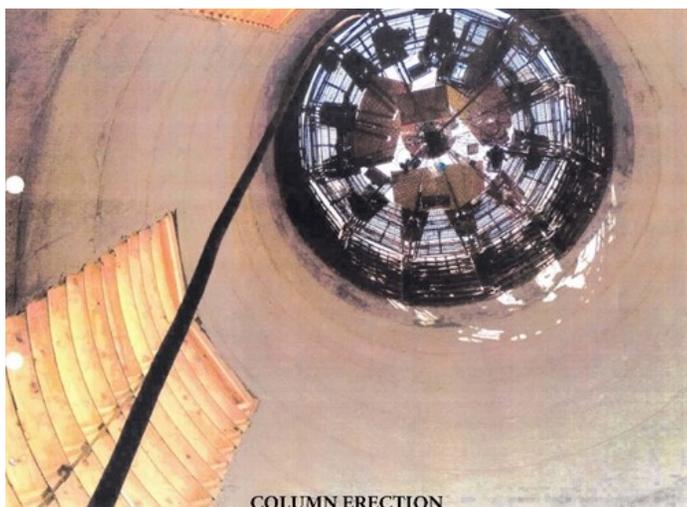
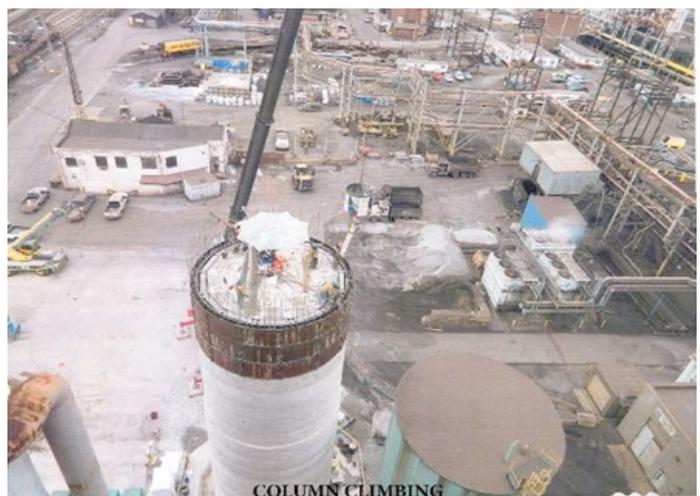
PROFILE OF FOUNDATION SHOWING IRREGULAR CONFIGURATION AS WELL AS IDEAL CONCENTRIC LOCATIONS FOR MINI PILES

**CONCRETE COLUMN**

The concrete column was designed plumb without taper and for quick setup using minimal construction time. Michele Small, P.E., from our Port Smith office developed all concrete details. We used a modified silo type jump form system that could be operational well within one week of beginning to set it up. The foundation progressively reached its cure as we began setup and construction of the column.



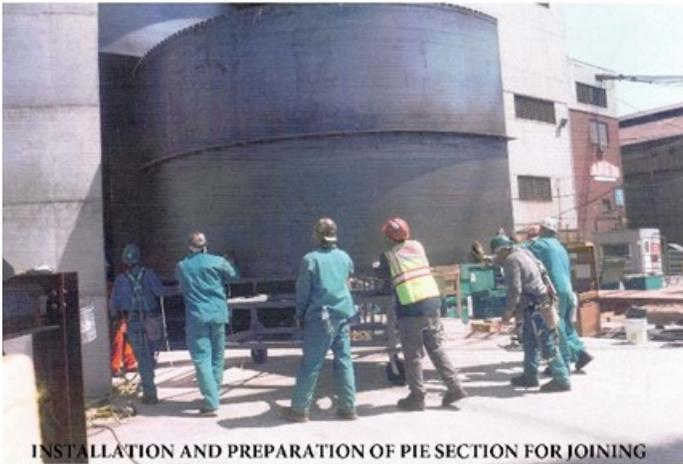
The column was built in four-foot jumps. Some days we achieved 12 feet. We have used this type of rig on other projects with similar requirements and had a proficient superintendent and crew that understood the required moves. Demobilization of this type of rig is also extremely rapid as it is setup to essentially lower itself. Fortunately this chimney size was able to lend itself to this type of construction without having to compromise a design other than using additional concrete to avoid more than one wall thickness change. For this type of rig, we use the easiest method for the change, reducing the section on the exterior. The other advantage of the silo type rig is that it requires smaller mobilization pieces, four-foot jumps, and consequently very hand-able equipment. Concrete is delivered from the exterior and can either be by our pre-engineered hoisting system or crane. Concrete is delivered by a rotating hopper on the deck into the forms.



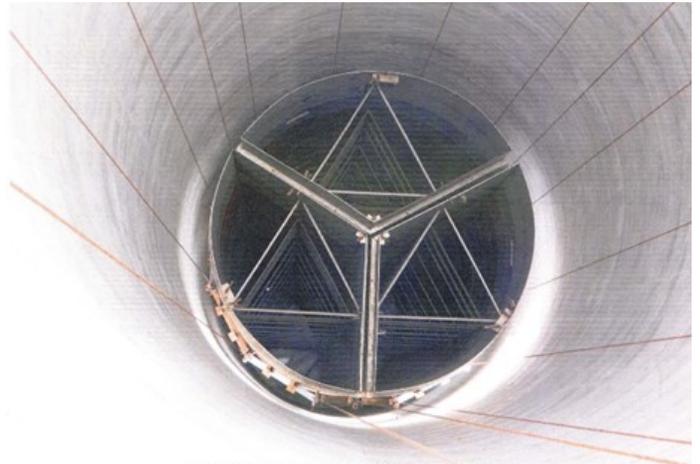
**UNIQUE STEEL LINER**

The liner from the exterior appears cylindrical, much like a normal steel liner of this diameter; however, in actuality the cylinder was made up three independently operating PIE SHAPED SECTIONS. One challenge in fabricating these sections was that they had to maintain proper stiffness to prevent deformation while being shipped, hoisted, and while being operated. The liner sections also had to be designed and fabricated so that welding that was necessary when the sections were inside the column was inside using back up bars, rather than on the outside due to lack of access. The cylindrical exterior piece of the

Many different corporate resources were used for the rapid completion of the design work; however the biggest challenge was a fabrication schedule, which would meet the project time requirement. Our local team from our local office, lead by Pat Jenkins and Ted Lansberry, was able to procure and qualify four different shops in order to meet the schedule. Dimensional control was key, as it was necessary for proper fit, from shop to shop, as well as stainless to carbon. Sections were designed for trucking challenges as well as they had to be able to make it to the job site in an efficient manner. The plant had many narrow passages as well as obstructions such as low pipe bridges.

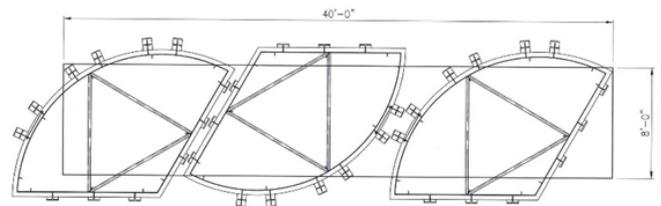


**INSTALLATION AND PREPARATION OF PIE SECTION FOR JOINING AND JACKING**

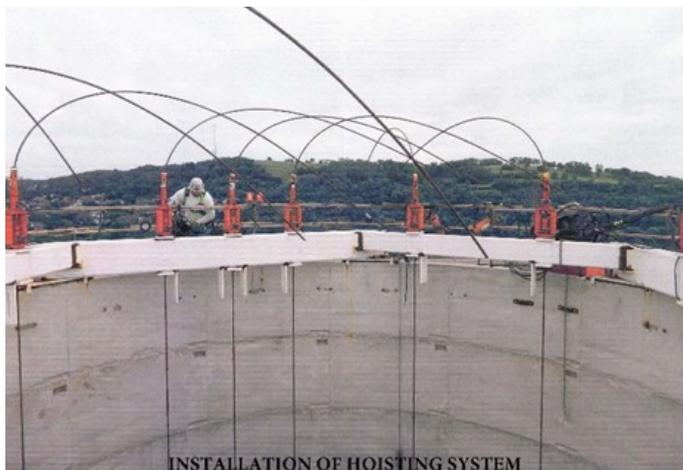


**INSTALLATION OF LINER SECTIONS**

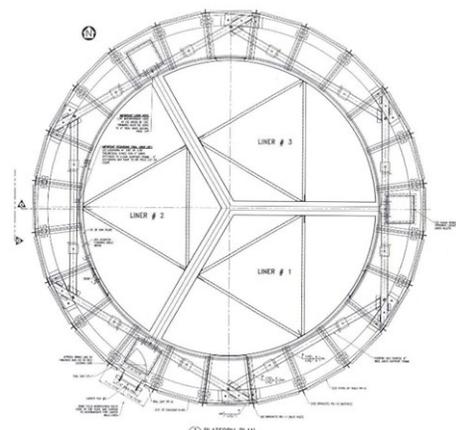
pie was in close proximity to the concrete column with minimal air space. It was necessary to allow for dampening and provide for protection from impact damage. A bumper system was designed and used. These pie shaped pieces had to be shippable and installable, in a size that could be efficiently brought to the job site, yet complete enough that field work was minimized. Almost all sections were hoisted with a Strand-Jack system after being maneuvered in the base of the column on custom designed dollies. The hoisting ring remained as part of the support structure. Most all welding was performed at or near grade. Although non-conventional due to the shapes, jacking was done in the traditional manner. Stainless was used for the section protruding above the column, while carbon steel was used for the section protected by the windshield. The exterior stainless portion with a carbon connection and the integral hoisting beam was installed over the top and lowered to the base. This allowed the stainless section to protrude and the lifting beams to be used as part of the permanent installation.



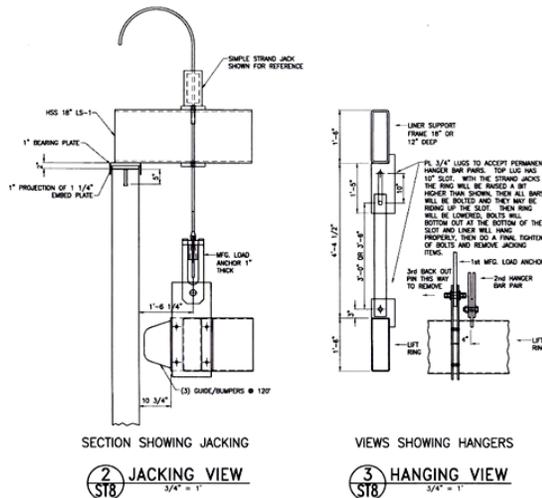
**FABRICATED PIE SHAPED LINER SECTIONS INCLUDING STIFFENERS THAT REMAIN AS WELL AS WALL BUMPERS AS LOADED ON TRUCK FOR SHIPMENT**



**INSTALLATION OF HOISTING SYSTEM**



**TOP VIEW SHOWING SUPPORT FOR JACKING AND PERMINENT INSTALLATION AS WELL AS FINAL CONFIGURATION OF THE THREE INDEPENDENT PIE SHAPED LINERS**



TRANSFER OF LOAD FROM JACKS TO HANGER BARS

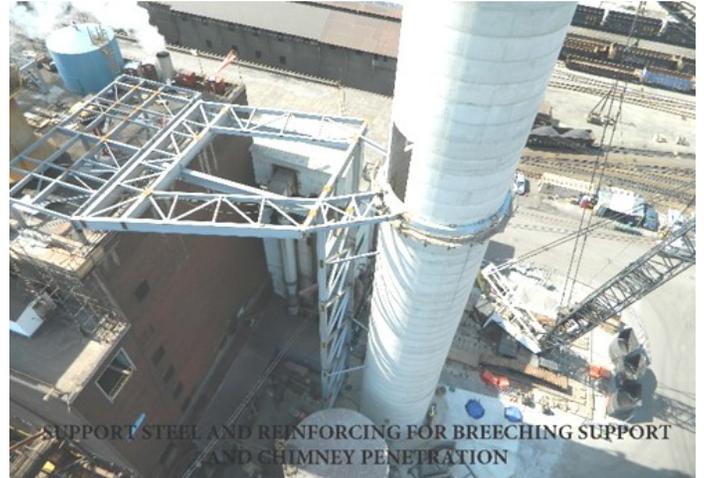
**BRECHINGS**

There were three unique breaching entries and configurations. The differences were in design profile and entrance location. This all involved extensive separate engineering for each unit both relative to the openings in the column, the unusual shapes, and required support. Handling, placement, and alignment required a lot of small equipment, precision operation, and extremely experienced personnel. Even the drain system was unusual and custom.

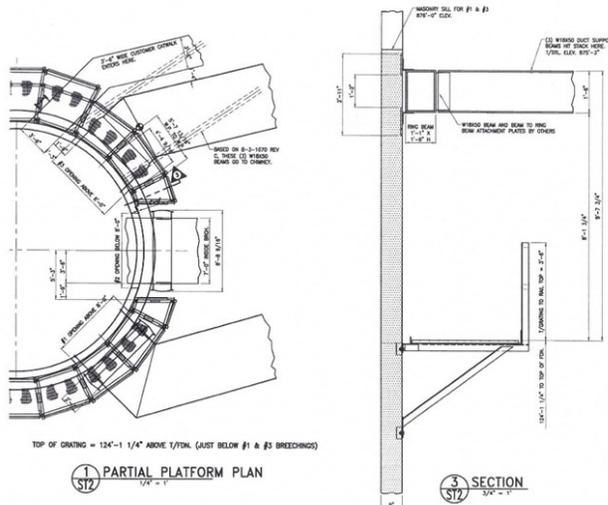
In some portions of the work, we were able to utilize an extremely large crane that was set up by others for work not in our scope or footprint. We pretty much lived on the site 24/7 while various corporate specialists moved in and out as required. Much of the steel erection was using our talented regular boiler maker personnel under the direction of our Tony Jackson leading the day shift and Mike Hess supervising the night shift when most all welding was performed.



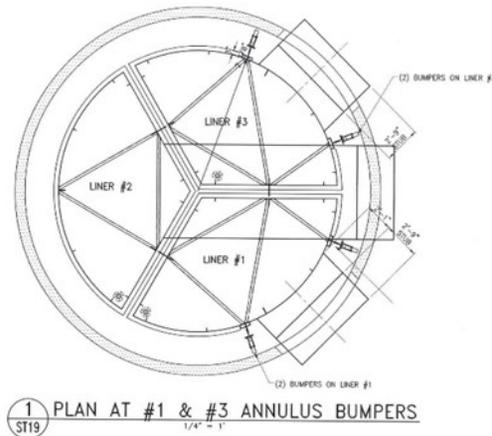
INSTALLATION OF BRECHINGS



SUPPORT STEEL AND REINFORCING FOR BRECHING SUPPORT AND CHIMNEY PENETRATION

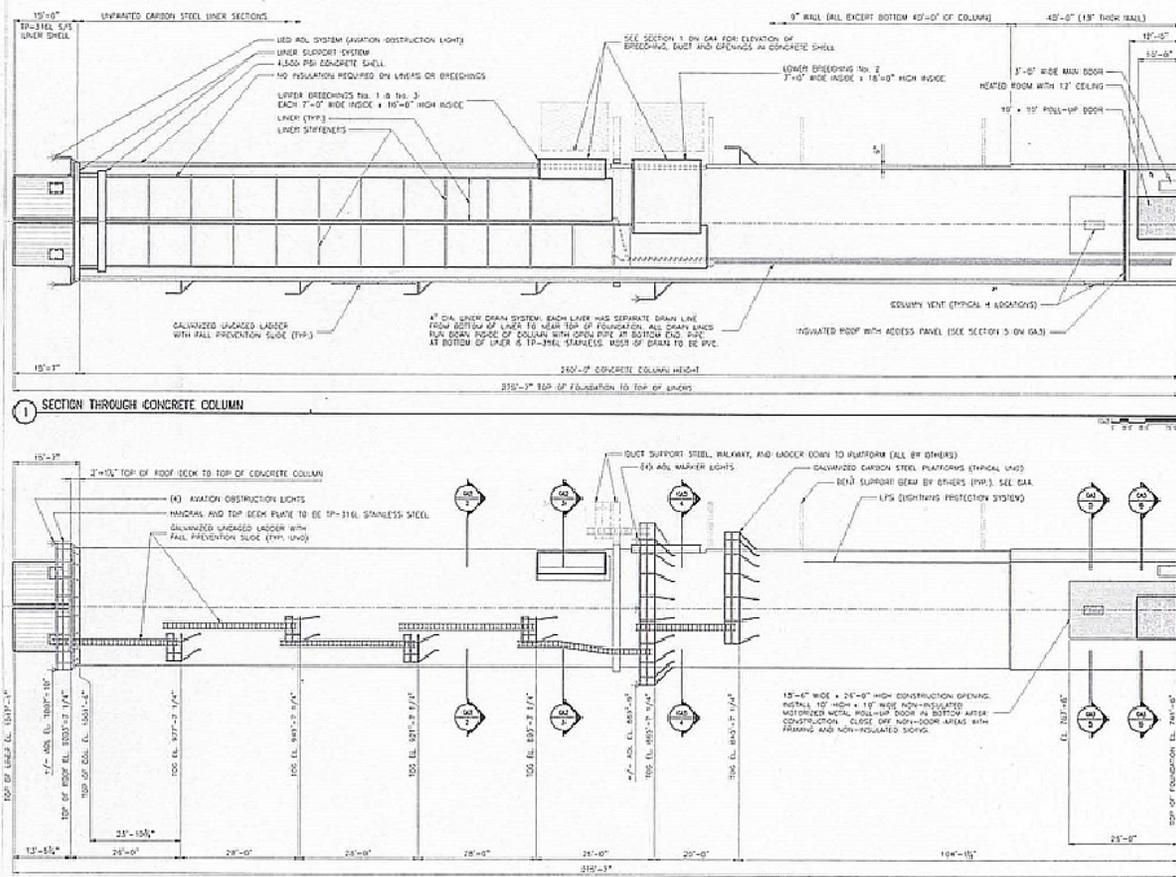


ADDITIONAL REINFORCING FOR BRECHING RETROFIT



1 PLAN AT #1 & #3 ANNULUS BUMPER  
 1/4" = 1"  
 PIE SHAPED LINERS INSTALLED SHOWING VARIOUS LAYOUTS OF BREACHINGS, BUMPER, ETC.

COMMISSIONING



FINAL AS BUILT WITH THE EXCEPTION OF EXTERNAL BREACHING SECTIONS & SUPPORT

In order to meet the mandate, commissioning was performed on a progressive basis with close cooperation of the power plant operators. Proofing and testing for independent expansion and contraction, and support systems, etc., was done on the fly, which would be normally considered an uncomfortable fast track. While maintaining the ability to stop and adjust, we did everything possible to avoid the necessity as time was so critical. The chimney performed admirably, meeting all requirements. In essence, all was smooth, with the exception of some unexpected vibration in the liners that we were able to correct.

I've left out some of the normal construction that was included such as ladders, platforms, supports, lightening protection, obstruction light requirements, etc as all of this was not specifically unique to this project. This project, although not extremely large, involved a large percentage of our experienced personnel performing their specialty. It required the confidence of ICC-Commonwealth as a group to take on the challenge and guarantee the performance. We are extremely proud of all involved and without question, have a more relaxed and appreciative, satisfied customer.

# HADEK

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**MAKING  
POWER STATION  
CHIMNEYS  
AFFORDABLE,  
RELIABLE AND  
EFFICIENT**



Coal fired power stations around the world are under pressure to improve their environmental performance. Hadek is their partner for preparing new and existing chimneys for operation under low temperature and/or aggressive conditions.

Visit [www.hadek.com/5-ideas](http://www.hadek.com/5-ideas) to get 5 suggestions for cheaper and more environmentally effective chimney construction and operation for coal fired power plants.

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### Paolo Zannetti

Paolo Zannetti is the President and Founder of EnviroComp Consulting, Inc.<sup>1</sup> and the non-profit EnviroComp Institute<sup>2</sup>. He is also the Director of the Air Pollution Scientific Initiative (APSI)<sup>3</sup>.

Dr. Zannetti has performed studies and scientific research in environmental sciences for five decades. His major field of investigation and competence is air pollution.

His activities have covered pure research in the fields of atmospheric sciences and numerical modeling, publications, seminars and courses, project management, environmental consulting, editorial productions, and expert testimony. He has written 300+ publications, and 40+ books and book chapters, including the book "Air Pollution Modeling"<sup>4</sup>, which was the first comprehensive book in this field and, still today, is a widely used textbook. A 4-volume, multi-author, revised and expanded edition of this book has been published<sup>5</sup> during the period 2003-2010 under his direction and chief editorial management.

Dr. Zannetti has studied air quality problems all over the world, often using computer models to simulate the transport and fate of atmospheric chemicals. In most of these cases, he simulated ambient concentrations using his own computer models and/or those developed and recommended by government agencies, such as the US Environmental Protection Agency (US EPA).

In addition to his academic and scientific achievements, Dr. Zannetti is very familiar with litigation consulting and has provided testimony in depositions and courtrooms in more than 60 cases.



### Giuseppe Bucci

is the Founder and Principal of Sinapsi Innotec Srl, an Italian consulting company specialized in Mechanical and Energy Engineering.

He graduated in Mechanical Engineering at the Polytechnic University of Milano, Italy. During his professional career, he specialized in Heat Transfer and

Fluid Dynamics mathematical modeling. He gained competence in Thermal and Fluid Flow Engineering using CFD techniques combined with experimental data. A significant part of his professional work has been focused on validation of numerical simulations to get reliable results for engineering design. His competence in CFD derived both from the development of his own simulation codes and the use of commercial ones. He also developed 1D mathematical models based on lumped parameters to efficiently study many problems related to Heat Transfer and Fluid Flow.

He has established collaborations with universities, in particular with the Polytechnic University of Milano and the University of Ferrara, to develop research projects for industrial applications.

His professional career has included consulting projects with primary companies in the oil & gas industrial sector, geothermal energy, heat exchangers, industrial valves, boilers, chimneys, and silencers.

He currently makes his professional experience available to support the development of projects and industrial products and also to organize the growth of R&D departments in companies where Fluid Dynamics, Heat Transfer, and new and efficient design methods are key factors for success.

## Reducing Air Toxic Impact from Power Plants Startups through CFD-Assisted Design of Chimneys

*Paolo Zannetti, The EnviroComp Institute  
Giuseppe Bucci, SINAPSI Innotec Srl.*

### Abstract

This paper examines the increasing use of power plants as backup systems for renewable technologies, such as wind and solar power generation. During periods of high energy demand or conditions where renewable technologies are insufficient, natural gas-burning power plants are needed to supply extra power generation. Under this scenario, power plants may be required to work with frequent startups, which cause higher ground level concentrations of air pollutants since, during startups, exit plume temperatures are lower than those during steady state conditions. Lower plume temperatures generate lower

plume heights and higher ground-level concentrations. Therefore, methods to speed up the attainment of steady state conditions should be investigated. One potential method is the internal lining of chimney, which is often performed to protect chimneys from damage and corrosion. We discuss the use of Computational Fluid Dynamics (CFD) techniques to simulate gasses inside a chimney with and without lining. We expect to use CFD methods in the future for a quantitative assessment of air quality benefits of lining.

## Introduction

Power plants burning natural gas can reach full load in less than an hour<sup>1)</sup>. Yet, with a cold start, several hours may be needed for the exit plume from the power plant stack to reach maximum steady-state temperature. Therefore, the transient period is characterized by a stack plume with lower temperature, causing lower plume height and consequent higher ground-level downwind concentration of air pollutants.

For example, we performed a simple calculation using the US EPA model SCREEN3<sup>2)</sup> under the following scenario:

- Flat terrain
- Stack height of 50 m
- Plume exit velocity of 10 m/s
- Internal exit diameter of 7 m
- Exit plume temperature of 60 °C (startup) and 90 °C (steady state)

Results show that, in typical daytime (unstable) and neutral atmospheric conditions, the maximum ground-level plume concentration is about 50% higher during the startup conditions with an exit plume temperature of 60 °C. In complex terrain, the percentage increase is expected to be higher.

Therefore, we should explore methods and techniques to speed up the transient period, in order to reach a steady-state exit plume temperature as quickly as possible. For example, as discussed below, the dynamics of plumes inside a chimney during startup can be simulated using Computational Fluid Dynamics (CFD) methods.

## CFD Methods

Computational fluid dynamics, known as CFD, is based on numerical techniques to solve the well-known Navier Stokes equations, relating to the conservation of mass and momentum in fluid motion plus additional equations for heat transfer and turbulence.

CFD analysis is an effective tool for design support in many industries. It is used for industrial product optimization and for the design of plant components where fluid flow and heat transfer are important factors, such as in the aerospace, aeronautical, automotive, energy, chemical, electronic, and pharmaceutical industries.

CFD is now a fundamental tool in the R&D and Engineering departments for many reasons that can be summarized as follows:

- CFD allows to check the ideas to be developed still in their initial stage of design
- It reduces the costs of prototyping and laboratory tests
- It provides a clear picture of the phenomena developing inside various components and allows prediction and better understanding of the expected results of a project configuration, thus improving its final development

The partial differential equations of fluid dynamics require to be solved by numerical methods based on discretization of domain and equations.

CFD methods work following a typical scheme where the Physical Domain and the Physical Phenomena are at the top of a flow process that generates at the end a set of algebraic equations (Figure 1). The finest the discretization the bigger is the number of equations to be solved, up to several millions. The difference between the numerical

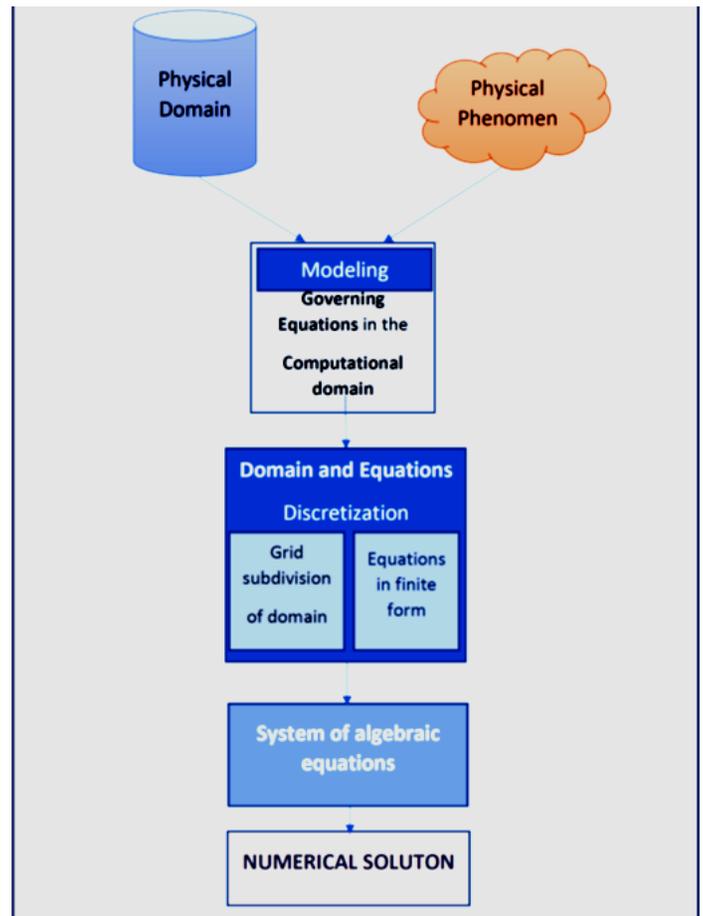


Figure 1: Typical CFD Flow Process

solution and the expected real value decreases asymptotically, so there is an optimum that balances computational effort and accuracy of results.

There are several discretization methods used to produce a numerical solution of fluid dynamics equations, but the most used is the finite volume method, well established thanks to its robustness.

An example of finite volume grid with cubic elements is shown in Figure 2 for the section view of a chimney.

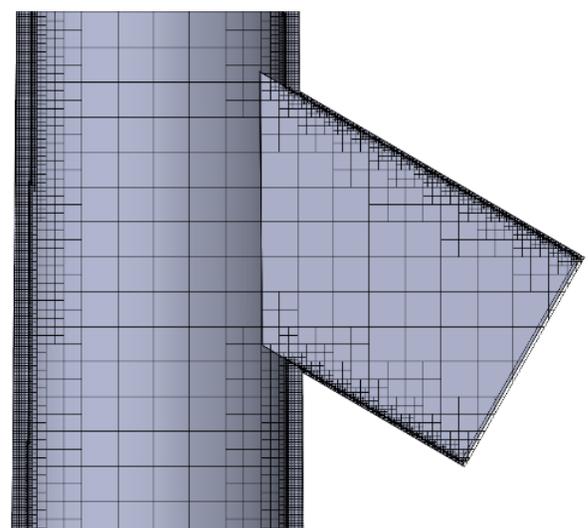


Figure 2: Example of Finite Volume Grid

### CFD Simulation of Gasses Inside a Chimney

CFD applied to chimney stack design can be a powerful tool to study and optimize:

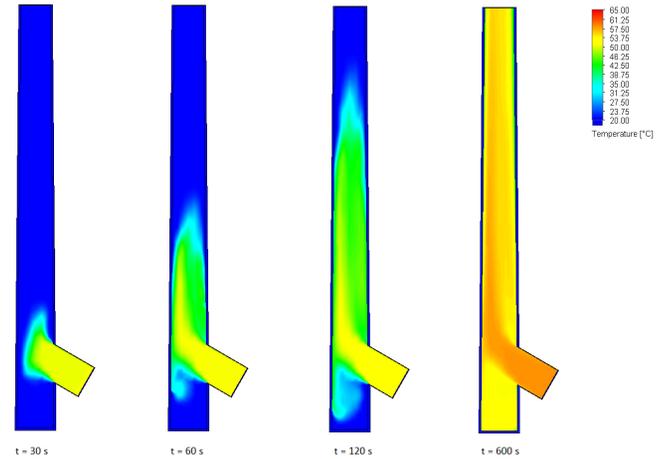
- the connecting flue pipe inlet angle, cross section area and shape, in order to reduce the local pressure drop
- impact and erosion problem in the inlet area inside the chimney
- non uniform temperature distribution and related stress, especially when connected to a gas turbine
- the pressure drop of the flow along the whole chimney
- the temperature distribution in the chimney wall and its thermal resistance
- the thermal resistance of composite walls, also with air gaps
- the outlet conditions of gasses flow, where velocity and temperature of outlet flow are an important input for air pollution dispersion models

For most design problems, CFD is applied for steady state conditions. However, CFD can also be used to simulate unsteady, transient problems, like in the scenario described below. Our goal, in fact, is the simulation of transient events during startup of a power plants. These events are characterized by flue gases at the inlet of the chimney that vary with time since velocity, or mass flow, and temperature change due to the warmup procedure need to bring the power plant gradually and safely to steady-state conditions.

As a result, the outlet values of flue gases velocity and temperatures vary in time and hours may be needed to reach a steady state condition inside the stack.

The CFD simulation allows us to evaluate transient conditions with different internal wall properties of the chimney, such as density, thermal conductivity, specific heat, and roughness.

An example below shows the outlet profile of flue gases temperature (Figure 3) with a chimney 100 m high and with inlet velocity and temperature linearly increasing. Figure 4 shows the temperature distribution inside the chimney during transient startup conditions. A longer time will be required to achieve full steady-state conditions at the exit top of the chimney



**Figure 4: Temperature distribution inside the chimney during transient startup conditions**

### Lining of Chimneys

Lining of chimneys of fossil-fired power stations provides a protection of a chimney’s inside substrate (e.g., steel, concrete, fiberglass, ceramics). Protection include chemical, temperature, and thermal shock resistance. For example, borosilicate glass block lining system (BGBLS), commonly known as Pennguard, is supplied by Hadek Protective Systems and is typically applied to the internal surface of power plant chimneys, stacks, flues, liners, and ducts.

Lining is also expected to reduce the startup transient time needed to achieve steady-state exit temperature from a stack. With the increasing use of gas-fired power plants as a backup for intermittent wind and solar power, lining may become a necessary choice to minimize the extra ground-level air pollution impact during frequent startups.

### Conclusions

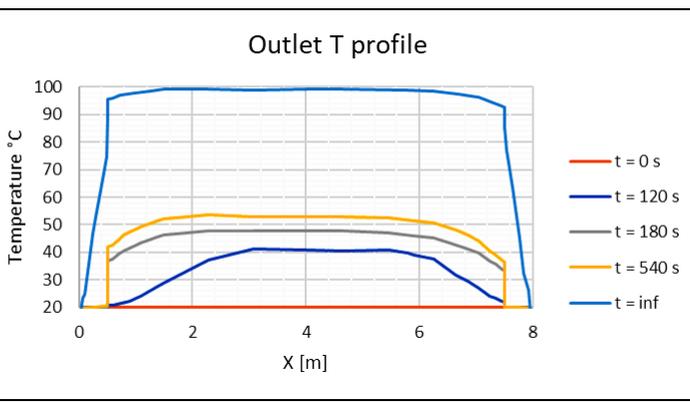
We have discussed the used of advanced CFD numerical methods to simulate the dynamics of gasses inside a chimney. Future applications of these methods are expected to quantify the air quality improvements expected from lining of chimneys of fossil-fired power stations under frequent startup conditions.

### Acknowledgments

We thank Albert de Kreij and Hadek Protective Systems for providing data, information, and support to this ongoing study.

- 1) E.g., <https://www.wartsila.com/energy/learn-more/technical-comparisons/combustion-engine-vs-gas-turbine-startup-time>
- 2) We used the SCREEN View™ version of the US EPA SCREEN3 model provided by Lakes Software <https://www.weblakes.com/products/screen/index.html>

<https://www.hadek.com/pennguard/industrial-chimney-lining/>



**Figure 3: Outlet gas temperature horizontal profile at the top of the chimney**



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**Karsten Grasmann,**

Is the technical director of Aero Solutions SAS. He studied mechanical engineering with the specialization of computer science in engineering at Ruhr-Universität Bochum focusing on simulation, numerical calculation, automation and robotics. He started his industrial career as a research engineer at GEA Energietechnik GmbH in 2006 responsible for numerical calculations and software development. In 2013 he received his Doctoral degree for the development of a technical swarm algorithm to solve pressure drop minimized tube-layouts in power plants. Since 2015 he joined Aero Solutions SAS as the technical director and he is responsible for the R&D-, engineering- and IT-departments.



**Alfred Heimsoth,**

is strategic product manager at keytech software GmbH. He studied physics at Ruhr-Universität Bochum and started his industrial career as software engineering in the area of product lifecycle management at the Ascad GmbH in Bochum. 1993 he was one of the co-founders of keytech software GmbH continuing his focus on software managing the lifecycle of technical products. Today – as a strategic product manager – he is responsible for the development and utilisation of new technologies on order provide customers

# Application of new VR/AR technologies within building and concrete inspection

A glance of the DT4M project -

*Karsten Grasmann, Aero Solutions SAS*

*Alfred Heimsoth, keytech software GmbH*

## Problem statement and project goals

The inspection of industrial constructions or plants, e.g., chimneys, cooling towers, etc. is mostly performed manually and documented in a combination of paper forms, photos and voice recordings that are combined to the final inspection report after complex postprocessing steps. This procedure is labourious and the quality of the reports highly depend on personal preferences and working method. Standardization is difficult to achieve.

In general, it can be said that the analog character has some weaknesses in the execution of the inspection process. Since all information is provided in an unstructured way, the preparation of the inspection is time and resource consuming. Furthermore, the provision of the necessary supporting documents such as maintenance instructions or manuals in printed form is associated with some complications since these must be carried separately and the targeted provision of the information is only possible with some difficulties. The recording of anomalies consists of the analog documentation of defects and the digital recording of photos or voice records using a supporting device like a camera. The subsequent connection and management of these two sets of information is error-prone due to the temporal offset, mostly based on experience or the knowledge of the personnel carrying out the work and involves a great amount of effort. To log the inspection, the necessary information must be compiled from different sources and manually transferred into a document. All these problems in the inspection process lead to a reduction in efficiency and effectiveness.

The scope of the DT4M project – digital twin 4 maintenance – is to establish a continuous digital inspection process based on a digital model of the construction (e.g. the cooling tower) combined with an onsite inspection procedure that uses augmented reality technology to allow hands free convenient and quick identification of damages and contamination along with photos and speech memos. In addition, digital check lists guide the inspector through the necessary tasks. All actions are automatically documented.

Finally, the digital inspection findings are the source of automatically generated reports which can be presented to the customer immediately at the end of the inspection process and can be used to easily compare results of various inspections.

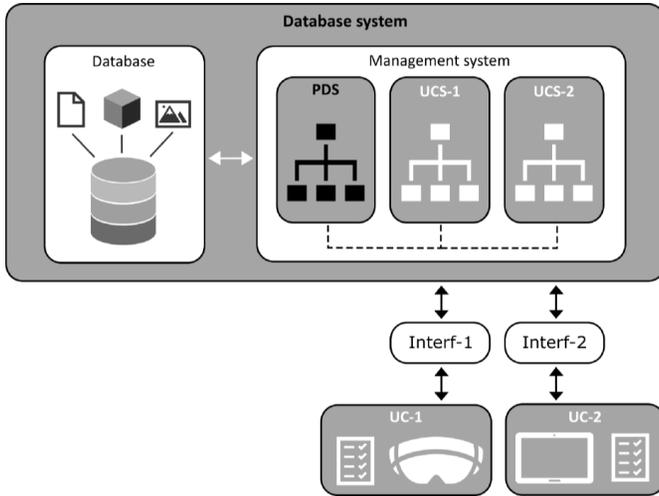
The project DT4M is executed by three project parties,

- Aero Solutions SAS (Industrial Background – Cooling Tower Development and maintenance)
- keytech software GmbH (Industrial Background – Software development)
- University Duisburg-Essen (Scientific Background)

This paper presents and overview of the current project, status of the project as well as an outlook on future activities.

### System architecture approach

This section presents a generic approach that can be used to support a usage- and metadata-based continuous information flow for any use case where object-related information needs to be provided, recorded, and secured. The required system architecture includes a database system, a device within a specific use case scenario that can meet the requirements for a digitally supported use case, and an interface to connect these subsystems.



**Figure 1: Concept for achieving a continuous flow of information related to the use case.**

Two basic structures are required for managing the database, a product structure (PDS) and a use case structure (UCS). In the product structure, the product is divided into suitable units such as components or assemblies. The product structure can be used to link all areas of the product lifecycle. However, it must be considered whether the product structure must already contain all the information required for the use case. If this is not the case, it must be extended at attribute level according to the respective use case. Product descriptive data and usage data such as drawings, operating instructions, 3D models or test plans can be assigned to the respective elements in the product structure. In addition, metadata such as part numbers, time periods or responsibilities can be stored at the respective elements of the product structure. In addition to the product structure, the concept for a continuous information flow includes a use case structure tailored to the use case scenario. The UCS describes an additional view of the product structure by assigning objects of the product structure to specific, use case-related units and enables the definition of the context by delimiting subareas. The UCS serves as a logical interface between the product structure and the use case (UC). Based on these structures, checklists can be derived by assigning corresponding measures to the respective units. In these checklists, all measures are displayed in a structured manner and corresponding information on the objects can be retrieved from the database system on the unit. This defined connection of the two structures thus enables the targeted referencing of all data and information between these two structures.

All application-related information and usage data such as manuals, instructions or technical specifications as well as the checklists are made available via an interface. This interface works bidirectionally, i.e., information can be retrieved from the database system and made available on the device as well as transferred from the device to the database system. The specification and properties of the interface depend on the management system used and the device.

The usage data mentioned for the respective object can be made available if the device can process the corresponding data formats. Regarding the consistency of the information, these checklists enable a complete definition of the object-related measures to be fulfilled and the information to be determined for these purposes. The context of the determined information can be defined in two different ways. First, it can be established through the checklist items that refer to corresponding entities in the use case structure. Second, the context can be established by directly capturing the real or virtual object in the respective use case scenario. Once a context is assigned to the collected information, the information exchange can either be performed in real time through the interface or transferred to the database system through a delayed connection. The real-time connection allows the information to be transferred directly to the database system during the inspection execution. In the case of a delayed transfer, the information is temporarily stored on the device and then transferred to the database system.

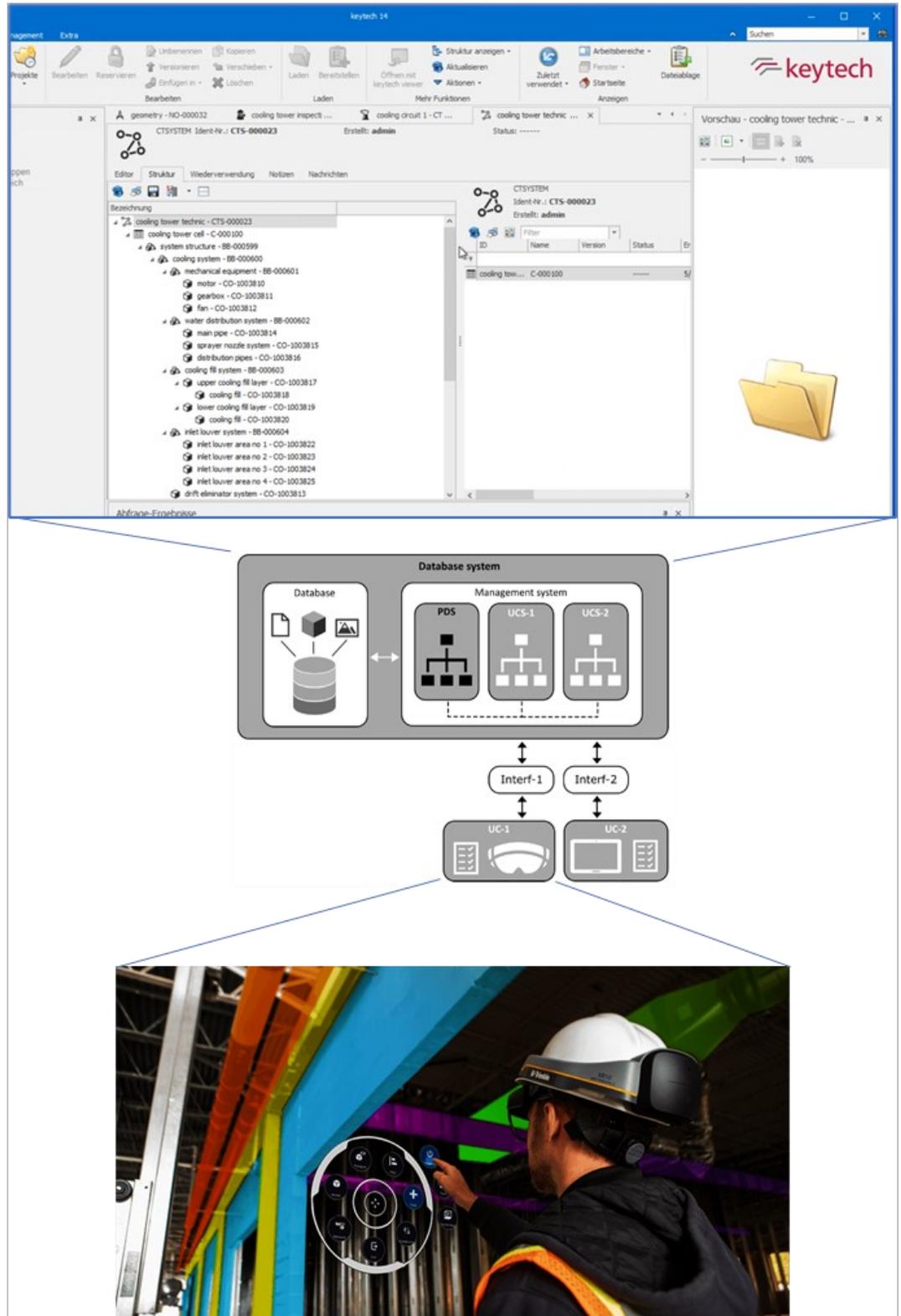
By linking the use case structure with the product structure, all information and results determined and collected during the use case can be transferred to the database system and thus referenced to the respective elements of the product structure so that they are available for future process steps. After this step, the cycle of a use case was completed, i.e., a continuous flow of information was achieved, as the concept enabled the provision, use and return of information related to the product.

### Future inspection process

In order to face the above-mentioned challenges for the inspection process of a cell cooling tower a system architecture was developed to take advantage of the AR-benefits for the inspection process and, in combination with the keytech PDM system, obtain a high-quality inspection process. To execute the future inspection process, following steps need to be executed under the premise, that the steps 1-2a only need to be done once since all these information is available for subsequent inspections.

1. Development of a digital representation of the construction based on templates that represent the different type of construction.
  - a) Product structure based on the Design BOM.
  - b) Use Case Structure to group areas or functional groups together.
  - c) Linking of both structures by referencing objects
2. Initialization of the structures using the following information:
  - a) Geometrical data, like dimensions, as precise as necessary. This information can be collected from the technical drawing or specifications.
  - b) Set-up of specific checklists for necessary inspection activities
  - c) Preparation of required supporting documents for the necessary inspection activities.
  - d) Assignment of Checklists and supporting documents to the appropriate inspection phase, checklist or object to ensure the targeted display during the inspection of a specific area or zone; exactly where they are needed.
3. Provide the possibility to adjust the information on site by the inspection personnel on their laptop in order to consider last minute information of the customer.

4. Transfer and initialization of the digital inspection data to the Microsoft HoloLens
5. Capturing damage with the help of Microsoft HoloLens.
  - a) Targeted provision of information such as checklists and help documents.
  - b) Creation or capture of a virtual reference point (context - object, level, etc.) incl. the location within the plant.
  - c) Digital capture of annotations (photos, videos, voice recording) and assignment to a reference point (context).
6. Transfer of the inspection results to the laptop of the inspection personnel and import to the PDM-System; Inspection results are automatically assigned to the related context.
7. Automatic logging of inspection results by exporting them to an appropriate template. Verification steps are necessary for finalization.
8. In addition, it is possible to display the results as a 3D model, with damaged elements highlighted in color. These models can be compared with the history to identify damage patterns or recurring damage.



**Figure 2:**  
 Display of system elements  
 within the DT4M-concept

## Benefits and restrictions

The development of an appropriate system architecture and the usage of modern technologies for the inspection of an industrial plant have many advantages for the applying company.

Reducing the inspection time on-site and reducing the amount of post inspection work leads to reduced inspection costs. Operators can do more inspections on their systems to increase the system functionality without multiplying the costs and downtime. A higher inspection density has a positive impact on environmental and economical issues. New HEAS regulations are easier to cope with.

By having an easy comparison possibility of different inspection results over time, damages by design, improvement options and life-cycle enhancements are easier to discover and the consulting quality on plant improvement enhanced.

### *Improved structuring*

- Information about the plant (product structure + maintenance structure)
- Tasks and activities (checklists)
- Inspection results (maintenance structure + checklists + results)

### *Improved planning possibilities*

- Assignment of documents to activities/checklists
- Reuse of structures and information
- Reduction of effort for recurring inspection activities on the same object

### *Improved reporting*

- Automated report generation
- Comparison of inspection history of facilities and specific objects
- Comparison of inspection history by overlaying 3D models with color highlighting of anomalies.

### *Restriction*

- High initial implementation effort
- System analysis to set up the system architecture.
- Parameterization of the structures
- Assignment of information to the structures
- Only for systems that can be structured well (subdivision into levels, functional assemblies without spatial separation); all components level/BG must be in the immediate vicinity.
- Only recommended if inspection of a specific plant is to be carried out recurrently.

## Outlook

This solution can easily be adopted to similar industrial construction objects. So, the advantages of the AR Supported Inspection and the 100% digital inspection report can be provided there as well.

Furthermore, the HoloLens is not the only tool of collecting inspection data. For instance, we can image using drones to collect inspection data of large object that is difficult to be inspected by man depending on the ability of the technology to provide us with appropriate position data.

It is also an option to provide the 3D Inspection report interactively on the Web Site in order to give the customer the possibility to browse through the inspection results.



### Wieland Beine

was born in 1961 in Hof/Franconia and still lives in this German city. After finishing the Junior High School, he started a professional education in manufacturing systems engineering. During 7 years at the German Air Force, he worked in radio engineering and used this experience to upgrade his education as a certified engineer in data processing technology in 1991. Then he moved the industrial sector and began to work in the fall protection systems industry. Wieland has worked in different positions, also as a design engineer to create comprehensive solutions for safety against fall on buildings, masts and chimneys. He has got experience in different companies in Europe, mostly in technical sales of fall protection systems, also for the international chimneys market and is proud to work for SKYLOTEC, a famous global supplier of fall protection solutions.

Wieland likes cycling, riding motorbikes, travelling and photography.

# Safe access on Tall Structures

*Wieland Beine*  
*SKYLOTEC GmbH, Neuwied, Germany*

## Introduction

Today, there is a distinction made in the market between two different kinds of ladder system for vertical access. A modern comfortable way to go frequently up and down is to use a motor-driven power ascender.

- Fall protection ladders, which include a rail for a fall arrester, stopping a fall immediately.
- Caged ladders: It just allows the person to lean back during a rest, there is no fall protection; now only used for low heights.
- Access on ropes with a motor-driven power ascender, for instance SKYLOTEC “ActSafe ACX”.



## Motor-driven Power Ascenders for Personal, Loads and Rescue

### 1. Personal Transport

Frequent ascents on towers leads to

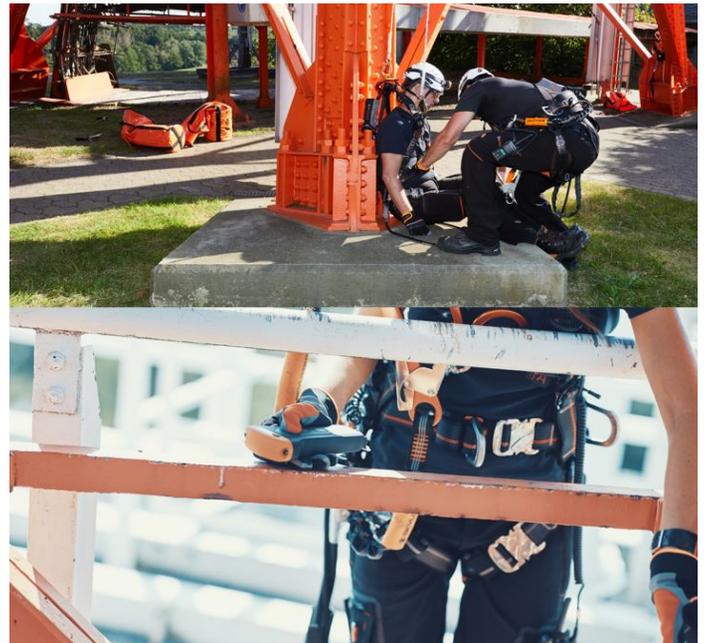
- High physical strain
- Repetitive strain injuries to personal

The battery-driven personnel winch offers vertical access without any muscular strength. This is a very comfortable way to go on top of tall structures. At the end, it is reduced workload for the staff and a reduction of physical strain or injuries. A rested technician is a safer technician. The device works with one hand operation, the rope insertion handling is very quick.

For safe working it is in any case necessary to work with an additional rope for fall arrest in case anything happens with the working rope.

In addition to lifting and lowering, centimeter-precise positioning is possible.

The ascent speed is max. 24 m per minute.



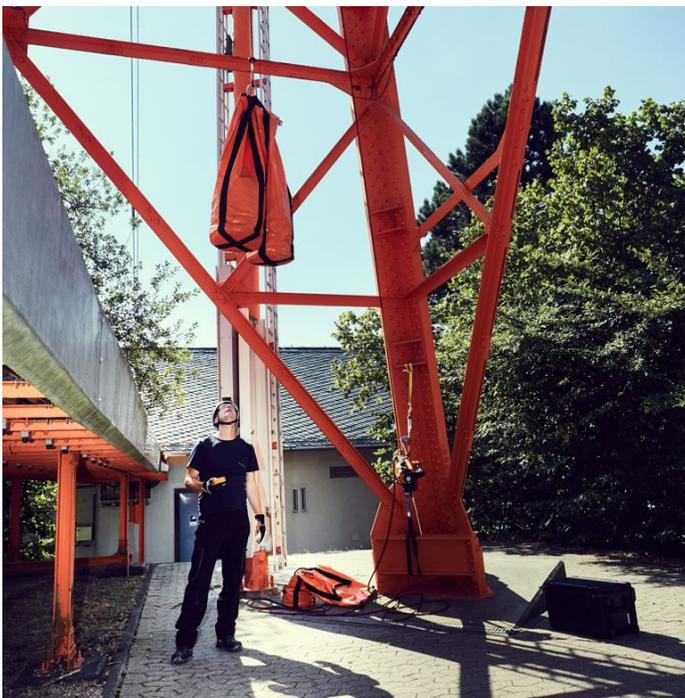
## 2. Simple Load Transport

### Compact lifting tool

for easy transport of devices, equipment or tools exactly to the place of use. Work load limitation of 200 kg can be doubled or by using additional pulleys and rope lengths as traction means.

The device is always stored in a box with remote control, second battery and carabiner. SKYLOTEC offers training in the safe use of “ACX” for personnel transport, rescue and load transport.

There is also a 4-stroke engine for use in extreme conditions.



**SKYLOTEC**

- Dimensions: 33 x 28 x 27 cm
- Max working load: 200 kg
- Ascent speed: 0 – 24 m
- Weight : 13 kg
- Water resident: IP 55
- Temperatur: -20 ° - +40°
- Lifetime battery: up to 5 years







Remote control  
and 2 batteries  
included





### Rescue

- Complex industrial rescue operations possible despite difficult access
- Fine adjustable speed control
- Remote control enables rescue from a distance
- Rescue team can be kept small by mechanical support; various possible application of the device at working height or also on the ground in combination with pulleys and remote control
- Horizontal and vertical transport of stretchers for rescuing persons is possible without any problems



### International and national regulations and requests for using motor-driven power ascenders:

At the international level, there are the ISO standards and the IRATA organisation that sets the standards. In addition, there are always local laws and regulations that need to be taken into account.

Organisation	Area		Dokument
ISO	International		<b>ISO 22846-1:2003</b> , Personal equipment for protection against falls - Rope access systems - Fundamental principles for a system of work
			<b>ISO 22846-2:2012</b> Personal equipment for protection against falls - Rope access systems - Code of practice
IRATA	International		<b>IRATA Safety Bulletin No. 49</b> Power Ascenders: The Hazards
OSHA	USA		<b>OSHA 1926.1441</b> - Equipment with a rated hoisting/lifting capacity of 2,000 pounds or less.
			<b>OSHA 1926.1431</b> - Hoisting personnel
DGUV	Germany		<b>German DGUV 212-001</b> states that winches are under the regulation of MaschVO
BAUA			 <b>TRBS 2121 Part 3</b> German technical regulation for safety at work - Hazards at work through fall, use of ropes for access and positioning
There are always local regulations and requests for safe work at height, which must be considered			

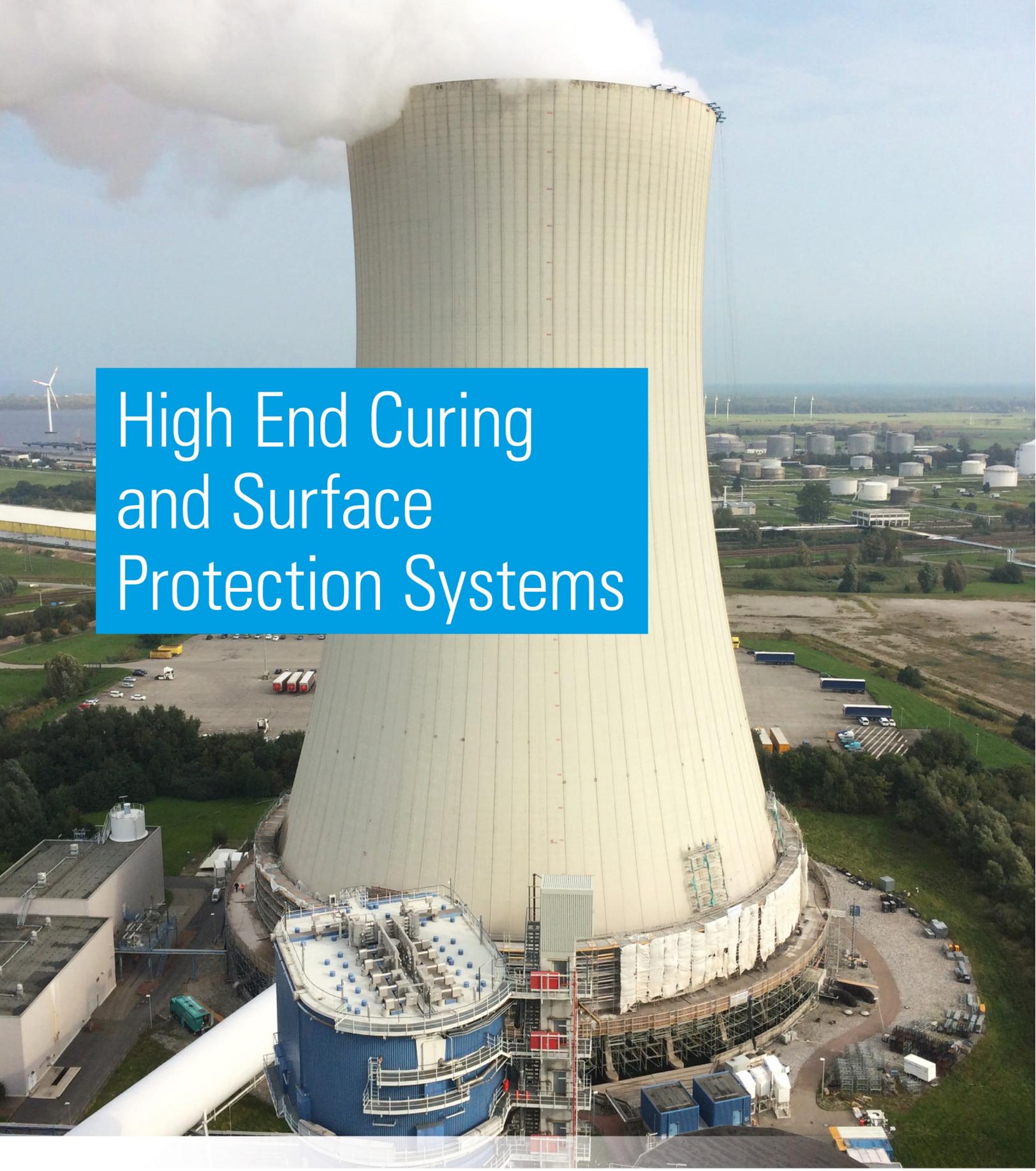
### Safety at work - Risk analysis

Any risk to safe working must be analysed and eliminated. The requirements and regulations are local and come from different local organisations. In Germany, the valid documents for this come from the **BG** (Berufsgenossenschaft / employee insurance association) and the **BAuA** (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin / Federal institute for safety at work and industrial medicine). The documents can be downloaded from their website.

### New innovative and unique products from SKYLOTEC

At low heights of 1.7 m – 3.2 m, conventional fall protection does not work. There is a new product, the **SKYLOTEC Airbag Protection Vest**, which reduces the risk of serious injury to a minimum.





# High End Curing and Surface Protection Systems

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- Highly efficient
- Scope for individual colour schemes

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BE SURE. BUILD SURE.



### Reinhard Martin

Born in 1963. Study of Civil Engineering at the University of Applied Sciences in Stuttgart, Germany. After gaining experience in the planning of infrastructure projects and a construction company he is working for MC-Bauchemie since 1994. Since 2009 focused on the concrete repair and surface protection of structures of the power generating industry.

# Surface Protection of a Flue in Wet Stack Operation

*Reinhard Martin  
MC Bauchemie*

## 1. Introduction

In Detmarovice, Czech Republic, ČEZ a.s. operates a coal-fired power plant with a capacity of 800 MW. Here, a desulphurisation was retrofitted in 1997. From this, a 264m high stack was erected, which has two flues and is operated in wet mode. After twenty years of operation, the joints of the ceramic lining showed severe abrasion and leaks, which caused acidic condensate to deposit on the outside of the flue.

For this reason, the first flue was repaired in 2017 and sealed and protected with the MC-DUR 1450 CP coating system, which is specially designed for this application.

The work in the second tube was carried out by Betochem s.r.o. in 2020. This article describes the execution of the work in detail.



*Figure 1: Chimneys of the power plant Detmarovice*

## 2. The coating system

The coating system is based on a duroelastic epoxy-resin. It consists of one primer each for steel surfaces and ceramic surfaces and the top coat, which ensures durable surface protection.

It is designed for the following criteria regarding to the VGB-Guideline R 634 U “Chimneys with wet-stack-operation”:

- temperature resistance during operation 45 – 63 °C
- temperature resistance during bypass-operation or in case of failure in the FGD 120 – 180 °C
- tolerance of rapid temperature changes both during start-up of the plant and switch on of the FGD
- resistance against sulfuric condensate with pH-value 2
- resistance against abrasive impact by dust particles and flue gas drops

Epoxy resins are usually two-component products, consisting of a base and a hardener component, which are mass-matched to each other. Before application the base and the hardener of the resin must be mixed together thoroughly, using slowly rotating mechanical mixers (appr. 300–400 rev/min) e.g. anchor shape mixers or paint mixers. It is recommended that the material after mixing should be filled in a clean container and briefly mixed again (“re-potting”).

They then two components react by polymerization to form a homogeneous matrix.

To ensure that this reaction can take place undisturbed, requirements for storage and processing conditions must be met. The resin is stored in a cool and dry place and can be stored for one year.

During the execution of the work, various important points must be observed in the individual work steps, which I would like to discuss in more detail below.

### 3. The single work-steps

#### 3.1 Substrate preparation:

The main purpose of substrate preparation is to create a load bearing surface for the planned surface protection measure. All constituent parts of the subsurface which have an unfavourable effect on its load bearing capability and adhesion are to be removed.

Depending on the condition of the substrate and the planned surface protection system, these objectives can be achieved by various methods. The most usual methods for the preparation of mineral substrates are

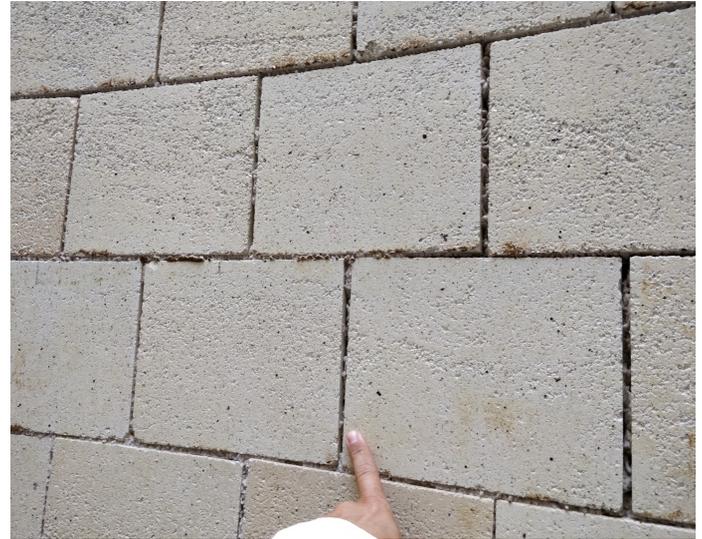
- High pressure water jetting: Here, the pressure and the nozzle must be selected in such a way that sufficient preparation is ensured without damaging the substrate. The advantage is that less blasting material is produced and there are lower costs for disposal. After high-pressure water jetting, care must be taken to ensure that the requirements for the application conditions of the coating resins, in particular the residual moisture in the substrate, the relative humidity and the dew point distance, are maintained.
- Grit blasting: The advantage of this process is that no water is introduced into the structure. The removal of existing coatings can be better controlled here, and a defined substrate can be produced more easily than with high-pressure water jetting. The costs for the disposal of the blasting material and the removal are higher.



**Figure 2: Substrate preparation using high-pressure water jetting**

After substrate preparation, pores close to the surface must be open, the substrate must have a fine-rough surface to ensure the adhesion of the surface protection system and to transfer stresses caused by temperature changes in bypass operation.

The requirements for the prepared substrate are as follows: pull-off strength  $\geq 1.5$  MPa average, lowest value  $\geq 1.0$  MPa, free from any contaminants, existing old coatings must be completely removed. Before the coating works start, the moisture of the substrate should be less than 6%.



**Figure 3: Prepared substrate with defects at the joints**

#### 3.2 Primer

The task of the primer is to ensure the adhesion of the coating to the substrate. For this purpose, the primer must be able to penetrate into the open pores of the substrate and penetrate the surface completely. It is usually applied by roller, in this project with a suitable airless spray technology, and then finished with the roller. In this process, any dust still present on the surface is absorbed into the primer resin and thus does not have a separating or adhesion-reducing effect.

The Graco Extreme airless spraying machine with a transmission ratio of 50:1 and a maximum pressure of 400 bar was used. Different spray nozzles were used depending on the weather conditions. The use of heatable hoses proved to be very effective in heating the coating resin to 30–38°C, thus ensuring optimum processing and a very good finish.

The following environmental conditions must be maintained during the application and hardening of the epoxy resin-based coating material:  $\geq 10$  -  $\leq 30$  °C air, material, substrate,  $\leq 85$  % relative humidity, 3 K above the dew point. Compliance with these parameters was permanently checked and recorded during the execution of the work. If the humidity is too high during application, the reaction of the resin will be disturbed, it will not meet the required properties.

If moisture or condensate accumulates on the surface of the freshly applied coating, this will also result in reaction failures and the formation of "carbamate", a layer of low strength and disturbing the adhesion of following layers, which must be removed in any case before the further work steps are carried out.

The consumption of the primer is depending on the roughness and the suction capability of the substrate. As a rule, it is 250–300g/m<sup>2</sup>. The primer must be recoated within 8–24 hours to ensure chemical adhesion of the following layers. If this is not possible, oven-dried quartz sand

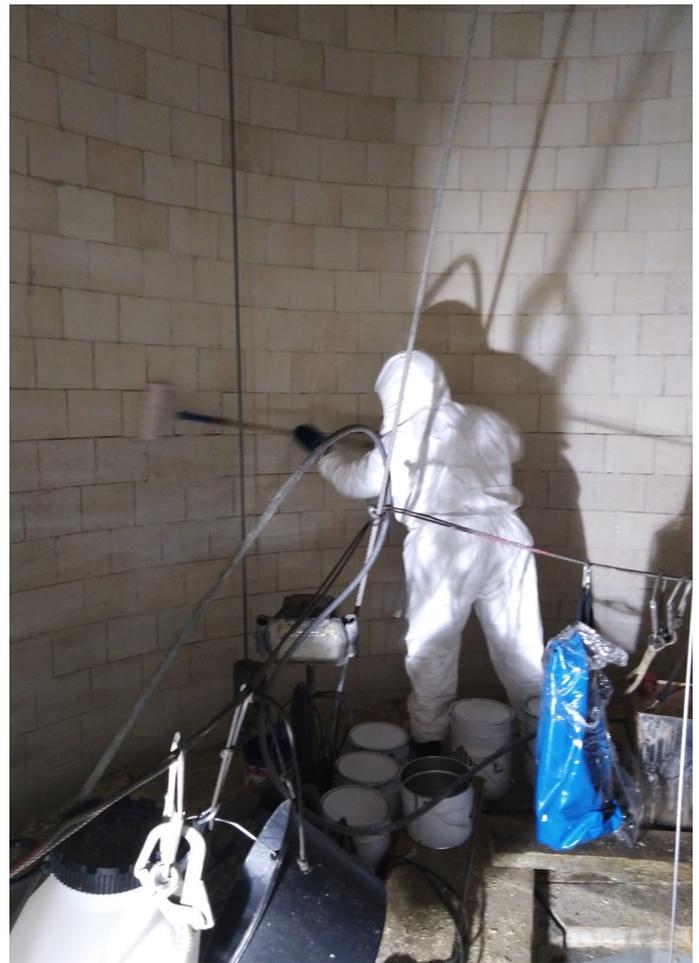
can be blown into the fresh primer. The resulting roughness allows mechanical bonding of the following coat. Alternatively, the already reacted primer can be reactivated by quartz-free granulate blasting or grinding before applying the further work steps.



*Figure 4: Mixing of the resin*



*Figure 5: Application of the primer using airless spraying technology*



*Figure 6: Finish of the primer with the roller*

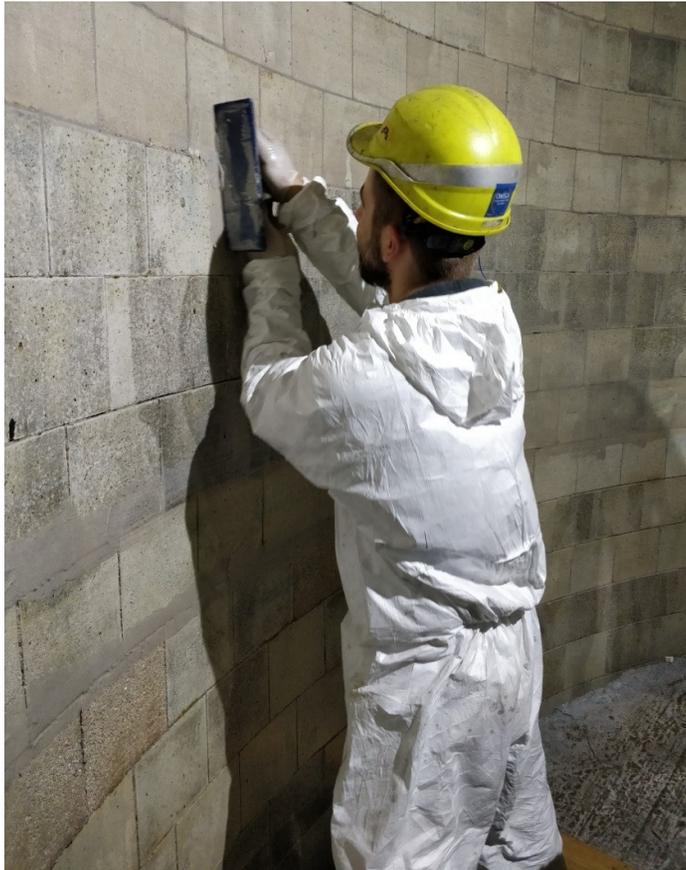
### 3.3 Filling pores and cavities, levelling of the substrate

Pores and cavities in the substrate must be closed and unevenness levelled to ensure that the top coat is applied in a homogeneous layer thickness and to avoid bubbles or other imperfections. Only in this way can the coating ensure durable surface protection.

For the pore- and levelling coat, the priming resin is filled up with oven dried quartz sand (0,1-0,3 mm) with a mixing ratio 1:1 p.b.w. and up to 3 weight-% MC-Stellmittel TX 19. is added to the mixture to get a thixotropic consistence. This makes it possible to fill even larger pores in the substrate or joints without the material sagging; the substrate is ideally leveled. Experience has shown that consumption is approx. 1,200 - 1,500 g/m<sup>2</sup> of finished mixture. In the case of heavily damaged surfaces, it is advisable to determine the actual consumption on the object.

The pore- and levelling coat is applied by hand. Steel trowels or a hard rubber board are used here, which allows the filler to be worked ideally into open pores and to level the surface.

The requirements for environmental conditions must also be complied with during this operation; the overcoating time is 8-24 hours.



*Figure 7: Application of the scratch coat by hard-rubber board*

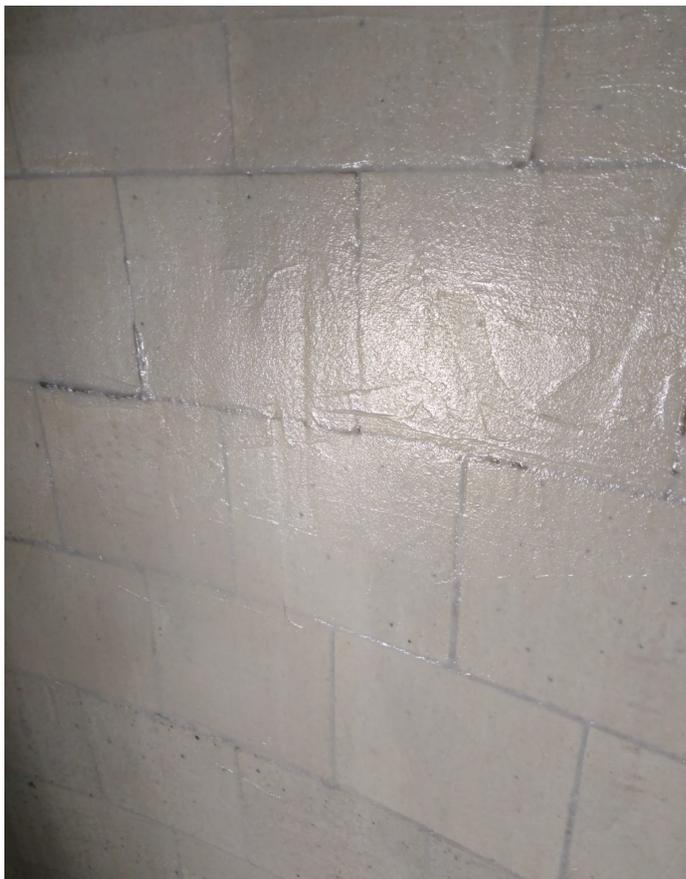
### 3.4 Top coat

The top coat itself ensures surface protection. It is important here that it is applied in the required layer thickness and, above all, evenly. For smaller areas, it is applied by roller in two coats of around 400 g/m<sup>2</sup> each. For larger areas, it is worth using the above-mentioned airless spraying technology, which ensures economical processing with an optimum result.

The requirements for environmental conditions must also be complied with during this operation; the overcoating time is 8-24 hours.



*Figure 9: Application of the top coat using airless-spraying technology*



*Figure 8: Levelled substrate*

## 4. Schedule of the works

The works were carried out in May and June 2020, lasting a total of 6 weeks. The substrate was prepared with high pressure water jetting at a pressure of more than 1,000 bar.

After the application conditions were met, the primer MC-DUR 1450 Primer C was applied with the airless spraying machine and re-rolled. In the second work step, the pore- and levelling coat was applied and finally the coating was airless sprayed in two successive work steps.

In order to ensure that the individual work steps were completed within the specified time, sections were worked on from a mobile working platform at a height of 25 m in each case. Initially, it took three days to complete such a section, but after the processes had become established, this interval was reduced to two days.

Unfortunately, the weather caused problems that had not been anticipated. An inversion weather situation with high humidity and dense fog caused cold air to fall into the chimney from above. As a result, the requirements for the application conditions could not be met and condensation formed on the surface of the freshly laid pore- and levelling layer on one section. The coating work therefore had to be interrupted for several days. Before they could be continued, the affected area was activated with grit-blasting to ensure the adhesion of the following layers. High-pressure water jetting was not used here so as not to introduce any further moisture. Only then could the top coat be applied by airless spraying.

Despite this interruption, the work was completed on schedule.



*Figure 10 and 11: Coated flue of the Chimney Detmarovice*

## 5. Conclusion

During the repair of the second tube in the chimney of the Detmarovice power plant, the coating work was carried out using modern airless spray technology. Although there were delays due to weather conditions, the work was carried out economically and completed on time.

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