SGC Rapport 2013:263

Compact and efficient gas-IR dryer for drying of paper and board

(Kompakt och effektiv gas-IR-tork för torkning av papper och kartong)

Hans Larsson, Stig Nodin

"Catalyzing energygas development for sustainable solutions"

Svenskt Gastekniskt CenterAB

SGC Rapport 2013:263

A COMPACT AND EFFICIENT GAS IR-DRYER FOR DRYING OF PAPER AND BOARD (KOMPAKT OCH EFFEKTIV GAS-IR TORK FÖR TORKNING AV PAPPER OCH KARTONG)

Hans Larsson, Stig Nodin

Denna studie har finansierats av:

Energimyndigheten
Maxrad AB
Innovatum AB
Tonsberg Maskinteknik
Nodin Synergieffekt AB

Postadress och Besöksadress
Scheelegatan 3
212 28 MALMÖ

Telefonväxel
040-680 07 60

Telefax
0735-279104

E-post
info@sgc.se

Hemsida
www.sgc.se

Svenskt Gastekniskt Center AB, SGC

SGC är ett spjutspetsföretag inom hållbar utveckling med ett nationellt uppdrag. Vi arbetar under devisen *"Catalyzing energygas development for sustainable solutions"*. Vi samordnar branschgemensam utveckling kring framställning, distribution och användning av energigaser och sprider kunskap om energigaser. Fokus ligger på förnybara gaser från rötning och förgasning. Tillsammans med företag och med Energimyndigheten och dess kollektivforskningsprogram *Energigastekniskt utvecklingsprogram* utvecklar vi nya möjligheter för energigaserna att bidra till ett hållbart samhälle. Tillsammans med våra fokusgrupper inom *Rötning*, *Förgasning och bränslesyntes*, *Distribution och lagring*, *Industri och hushåll* och *Gasformiga drivmedel* identifierar vi frågeställningar av branschgemensamt intresse att genomföra forsknings-, utvecklings och/eller demonstrationsprojekt kring. Som medlem i den europeiska gasforskningsorganisationen GERG fångar SGC också upp internationella perspektiv på utvecklingen inom energigasområdet.

Resultaten från projekt drivna av SGC publiceras i en särskild rapportserie – *SGC Rapport*. Rapporterna kan laddas ned från hemsidan – www.sgc.se. Det är också möjligt att prenumerera på de tryckta rapporterna. SGC svarar för utgivningen av rapporterna medan rapportförfattarna svarar för rapporternas innehåll.

SGC ger också ut faktabroschyrer kring olika aspekter av energigasers framställning, distribution och användning. Broschyrer kan köpas via SGC:s kansli.

SGC har sedan starten 1990 sitt säte i Malmö. Vi ägs av E.ON Gas Sverige AB, Energigas Sverige, Swedegas AB, Göteborg Energi AB, Lunds Energikoncernen AB (publ) och Öresundskraft AB.

Malmö 2013

Martin Ragnar
Verkställande direktör

Swedish Gas Technology Centre, SGC

SGC is a leading-edge company within the field of sustainable development having a national Swedish assignment. We work under the vision of *"Catalyzing energygas development for sustainable solutions"*. We co-ordinate technical development including manufacture, distribution and utilization of energy gases and spread knowledge on energy gases. Focus is on renewable gases from anaerobic digestion and gasification. Together with private companies and the Swedish Energy Agency and its frame program *Development program for energy gas technology* we develop new solutions where the energygases could provide benefits for a sustainable society. Together with our focus groups on *Anaerobic digestion*, *Gasification and fuel synthesis*, *Distribution and storage*, *Industry and household* and *Gaseous fuels* we identify issues of joint interest for the industry to build common research, development and/or demonstrations projects around. As a member of the European gas research organization GERG SGC provides an international perspective to the development within the energygas sector

Results from the SGC projects are published in a report series – *SGC Rapport*. The reports could be downloaded from our website – www.sgc.se. It is also possible to subscribe to the printed reports. SGC is responsible for the publishing of the reports, whereas the authors of the report are responsible for the content of the reports.

SGC also publishes fact brochures and the results from our research projects in the report series *SGC Rapport*. Brochures could be purchase from the website.

SGC is since the start in 1990 located to Malmö. We are owned by E.ON Gas Sverige AB, Energigas Sverige, Swedegas AB, Göteborg Energi AB, Lunds Energikoncernen AB (publ) and Öresundskraft AB.

Malmö, Sweden 2013

Martin Ragnar
Chief Executive Officer

Foreword

The project for a new gas IR dryer for the paper industry is mainly about engineering and design of an emitter, i.e. a device carrying gas burners and an integrated exhaust exit to be manufactured and tested in a pilot-coater machine for realistic trials on coated board.
The participating organizations of this project have been Maxrad AB, Nodins Synergieffekt AB, Tonsberg Maskinteknik and Innovatum AB. The project was started in September 2012, and completed in December 2012. Project leader and inventor has been Hans Larsson, Maxrad AB. Technical leader has been Stig Nodin, Nodin Synergieffekt AB and the engineering work has been carried out by Kaj Andersson, Tonsberg Maskinteknik,. Innovatum AB has supported the project through MD Tore Helmersson and project leaders Peter Zienau and Stefan Swedhem. It should also be noted that Leif Broberg, the owner of Brålanda Industrier AB, has meritoriously assisted in the project with production advice and services.
This project was initiated from a product idea and the engineering has been completed according to the time plan. Participating members of this project have reached the project target and created a new innovative product for drying of paper and coated paper in paper and coating machines.
The new dryer, based on infrared radiation, is mainly to be used in the paper industry. However, the drying concept is also well suited for other industrial processes where drying, heating and curing are the requirements. Examples are textile, printing and food industries.
A reference group has been appointed for the project with the following members and organizations. Anna-Karin Jannasch, SGC (administrator), Niklas Karlsson, Tremcel AB, Karin Nodin, Nodins Synergieffekt AB and Peter Zienau, Innovatum AB

Vänersborg, Sweden 2013

Maxrad AB/Hans Larsson

Summary

A new gas IR dryer was designed to provide high radiation power at an optimal wavelength for improved drying rates and quality improvements in paper- and board machines. The flameless combustion of fuel gas is emission free as a function of burner material used. The design also provides minimal risk of fire, stops contamination of burners and is easy to maintain.

Gas IR dryers are widely used in the paper industry. However, development of new and more efficient dryers has not followed the general development of the industry itself. Whilst the paper mills have raised their production, developed their products and improved product qualities, the conventional gas burner systems are more or less the same and have only grown larger in size with limited improvements of the drying capacity.

To reach an optimal result of physical performance of an emitter, new materials are necessary. New, high emissive materials, durable at high temperatures, provide considerable power output. Drying of paper or coated papers, produced in different qualities at high speeds, require high demands on a drying system. Installation of a conventional gas IR dryer need severe space in a paper machine, which most often is space limited, to compensate for low power density. The priority for a new dryer is to increase power density to a level where efficient drying can be done in a limited installation space.

Paper and cellulose fibers will not absorb any significant amounts of infrared energy at wavelengths shorter than 1.35µm. Energy between 1,35µm and 2,0µm is weakly absorbed where radiation penetrates deep into the sheet and heats the interior efficiently. At wavelengths above 2.0µm, absorption in the sheet is strong and the surface heats up fast causing overheating and fiber raise. The peak wavelength for the new dryer is aimed for 1.5-1.75 µm which is an optimal wavelength for drying of cellulose fiber. Conventional gas infra systems generate wavelengths of 2.2- 2.5µm and need careful temperature control of the sheet surface to avoid overheating.

To improve drying rates, high power at an optimal wavelength is necessary. It is also important to operate the dryer close to the running sheet for maximal radiation transfer. Radiation intensity is inversely proportional to the square of the distance from the source. Conventional gas IR dryers operate at a longer distance from the sheet as the emitters have an open face towards the paper sheet. The new gas IR dryer carries a transparent shield for infrared radiation and allows the burners to be positioned close to the sheet. The shield is continuously cooled and provides a minimal fire risk when facing the paper sheet. It also stops contamination of the burner surface where coatings and other particles would harm the function of the burner. Open face burners have to be maintained on a regular basis in similar situation and carry risks of fire, which demands extensive systems for fire appliance.

This project is about optimization of the drying process by increased burner power, optimizing the radiation wavelength and reduction of the burner distance to the paper sheet to have a better radiation transfer. Exhaust gases from the emitter are recycled resulting in higher efficiencies of the drying. Earlier trials of the burner material confirm high power, resulting in suitable wavelength for paper drying.

A trial unit is to be manufactured and tested in a pilot coating machine later this year. The market has already noted the advantages compared to conventional products, and interest has been shown from several representatives of the paper manufacturing industry.

Sammanfattning

Projektet avser utveckling av en gas IR-stork med hög effekt, optimerad våglängd och hög säkerhet vid torkning i pappers- och kartongmaskiner. I projektet har också ingått att anpassa gas IR-torken för framtida miljökrav vid förbränning. Torkning av papper och kartong vid tillverkning är energikrävande. Pappersindustrin är en av de industrigrenar som använder mest energi för att tillverka sina produkter.

Konventionella IR-torkar började utnyttjas för att torka bestrykningssmet i pappers- och bestrykningsmaskiner. Teknologin kompletterade de lufttorkar som normalt användes och innebar en kapacitets- och kvalitetsökning av produktionen. Elektriska IR-torkar, med hög effekt, har inte genomgått någon större förändring sedan de introducerades i pappersindustrin under 1980-talet. De senaste årens prisutveckling för elektricitet har kraftigt reducerat viljan hos pappersindustrin att investera i elektriska IR-torkar samtidigt som pappersindustrin befinner sig i en förändringsfas produktions- och energimässigt.

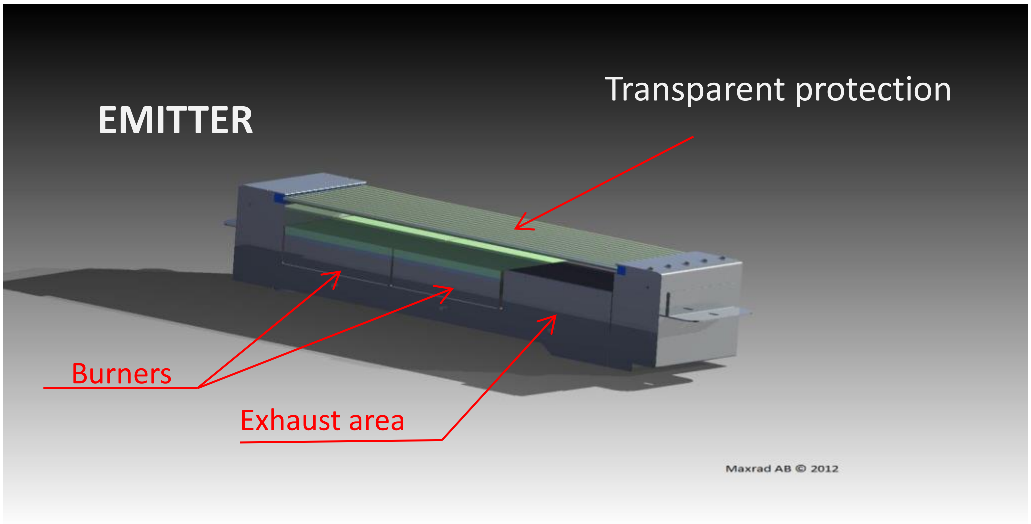
Gas IR-torkar har använts i sin nuvarande konstruktion i mer än 30 år. Brännarna är oftast konstruerade med en keramisk platta där gasen strömmar ut genom hål och antänds på en öppen yta. En ökad gasströmning innebär större flammor med risk för flamlyft, och vid mindre strömning föreligger risk för att lågan slocknar under drift.

Pappersindustrin har ett behov av effektivare och mer miljövänlig teknologi, vilket har varit ett av incitamenteten för projektet att utveckla en ny gas IR-tork med stöd, via SGC, från Energimyndigheten.

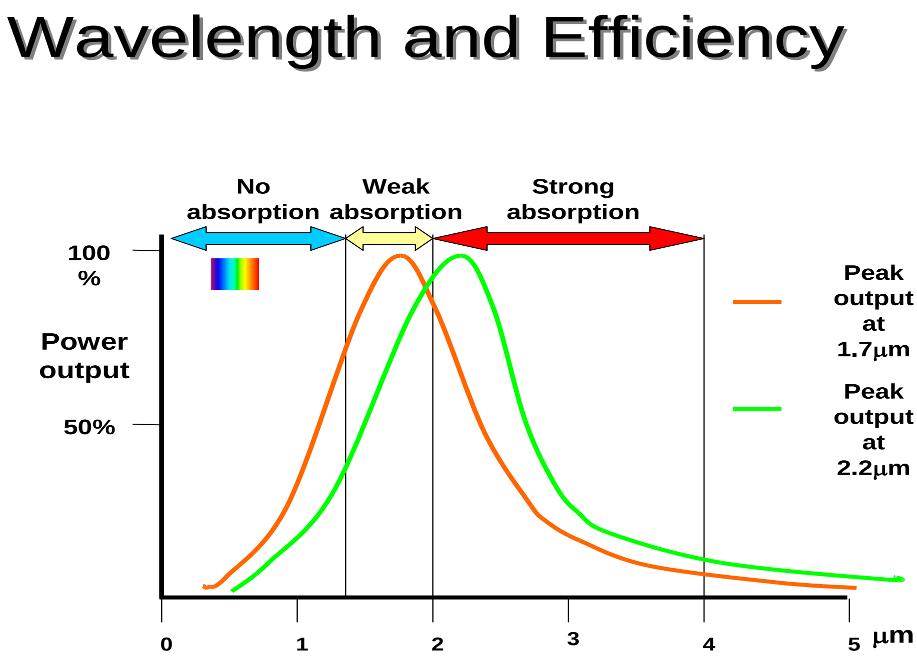
För att kunna utveckla en ny typ av gas IR-tork för pappersindustrin behöver följande uppfyllas:

1. En brännare som vid en högre temperatur kan utveckla högre effekt.
2. En brännarkonstruktion som medför en effektiv våglängd av strålningen för torkning av cellulosafiber.
3. Återanvändning av avgaser för att höja effektiviteten på brännarna.
4. En brännarkonstruktion som kan verka nära pappersbanan utan risk för brand för att erhålla bättre effektivitet.
5. Ett skydd som hindrar nedsmutsning av brännarytan för säker funktion

Den nya gas IR-torken innehåller flera emitterar. En emitter innehåller i sin tur två brännare, samt ett internt utrymme för återvinning av förbränningsgaser. Vid en temperatur av 1400°C utvecklar brännaren 3 ggr högre effekt än en konventionell brännare, vilken har en genomsnittlig temperatur av ca 1000 °C. I återvinningsdelen finns ett filter med hög emissivitet. Filtret värms upp genom evakuering av förbränningsgaserna genom detta till en temperatur som avger strålning mot pappersbanan. Övrig energi i avgaserna återanvänds genom att förvärma förbränningsluften, vilket ökar verkningsgraden av brännarna eftersom mindre bränsle går åt för att värma förbränningsluften. Genom konstruktionen av ett kylt skydd framför brännarna, kan en emitter placeras mycket nära pappersbanan för en effektivare överföring av strålningseffekt och våglängd till pappersbanan. Skyddet är transparant för strålning som genereras och utgör även skydd mot nedsmutsning. Brännarens struktur innebär en förbränning utan öppna flammor eller på brännarens yta. Förbränningen sker inuti ett flamhållande poröst material och är närmast fullständig.



Strålningens våglängd är en stor betydelse för hur effektiv torkning som kan genomföras. Våglängden vid en brännartemperatur av 1400°C absorberas djupt in i pappersbanan och ger en effektiv och jämn torkeffekt som gynnar kvalitet av såväl baspapperets ytskikt och bestrykningsskikt. Den utvecklade gas IR-torken kan användas i fler applikationer än tidigare såsom fuktprofilkorrigering och förvärmning för kapacitetsökning.



Optimal våglängd vid torkning av cellulosabaserade produkter.

Förbränningen är miljövänlig, och utrustningen uppfyller gällande och nu kända framtida miljökrav. Tidigare användning av gasol (Liquified Petroleum Gas, LPG) och olja har ersatts med naturgas (Liquified Natural Gas, LNG) vid flera pappersbruk. Användningen av naturgas i pappersindustrin innebär kraftigt minskade utsläpp i jämförelse med gasol och olja.

Gas IR-torken överensstämmer med industrins framtidssatsning. Genom att höja effektiviteten kan utrustningen begränsas i storlek och lätt installeras i pappersmaskiner.

Skyddet av brännarna gör att effektiviteten ökar i och med att utrustningen kan minska avståndet till pappersbanan jämfört med konventionell utrustningen. Skyddet är transparant för strålningen och kyls så att risk för antändning av pappersbanan kan undvikas. Nedsmutsning utgör inget problem på brännarna samt att tändningen av gas IR-torken är säker från extern påverkan.

Content

1. Background

The IR-drying technology is widely spread in the paper industry and accepted as an efficient tool for drying, heating and curing of paper and board products (9).
IR-dryers are used for special purposes in the production and shall be considered as complementary drying rather than a replacement of traditional drying methods (9). IR-drying is regularly used for coating drying after coaters, for profiling of uneven moisture content cross the paper sheet after the drying section and before reel and pre-heating for incremental drying (5). Conventional IR-drying systems on the market are electrical or are using fuel gas to generate infrared radiation (9).

The consumption of paper products are expected to increase over time, and the number of production sites and machines are expected to decrease. The prognoses are built on the expected growth of population and the fact that countries, that historically have consumed very little paper per capita, will increase their consumption in line with the total development of living standards. This will result in new machines to manage the demand for an increased production, improved quality and new products will take place over time in those paper mills, which intend to stay competitive in the future (10).

Use of gas IR dryers in the paper industry has a long history. More than 30 years ago, gas IR-dryers were used by the paper mills (*2).* High power, electrical IR-dryers were introduced to the market in the early 80-ties (*5*). It was mainly a result from the increase of oil prices some years earlier. The prices of electricity and oil became more or less equal, and the high power electrical dryers became an alternative on the market.

Today, the situation has changed once again and electricity is now expensive and the use of oil is limited in many paper-producing countries. Fuel gas is an important energy source and it is expected to grow further in importance using liquid natural gas (LNG) (1).

Additional reason for developing a new gas IR-dryer is the environmental aspect (4). The paper industry is a major consumer of fuel gas for their production of paper. Different types of fuel gases are used, but most frequent is Liquified Petroleum Gas (LPG). The use of fuel gas is increasing in many industries while oil will continue to be phased out. It is also expected that fuel gas consumption will increase as a result of new distribution methods of Liquified Natural Gas (LNG) and because of its reduced impact on the environment using this fuel gas (*7*). Co-combustion with gases such as biogas and/or hydrogen is interesting in order to decrease the environmental impact further.

2. Aim

The aim of this project has to develop and to construct a pilot gas-IR-dryer, which has a high power density and an optimal wavelength for efficient drying of coated and uncoated paper and board. Later, it will be used in a following pilot-test at a given pilot coating.

3. Methodology

The following steps have been involved in the development of a gas IR-dryer:

- Studies of literature from experiences of drying paper with infrared technology and anticipating problems involved in the process.
- Previous experience, report SGC 164.
- Knowledge gained in cooperation with IKTS Fraunhofer Institute AG.
- Knowledge from previous projects will be an important element in the design of the pilot gas IR-dryer, since the primary target has been to use it in different steps of the paper/board manufacturing process.

Engineering, such as material selection and design details, will be important parameters when creating the right conditions for the burners in order to achieve the necessary performance.

Compilation of information and experience has supported the dossier preparation of the development of a prototype. The main focus has been to verify that the gas IR-dryer achieved functionality and performance as requested.

The individuals involved in the project have contributed with skills in design, technical advice and project management, internal competences, while external sources have contributed with expertise in production, engineering, design experience, installation and management of gas systems.

The work has been conducted by an interactive collaboration between the involved competences and the engaged installation company that has an extensive knowledge of the paper industry.

A reference group has been used to examine the situation and supply opinions and perspectives for necessary changes in the project.

Design evaluation (iterative work) has been conducted continuously by the competences involved and the solutions have been discussed to ensure functionality. Through this method, all experiences have been used, in the early stages of production and mistakes could be minimized in the long run. Partial solutions have been developed for the planned production to be able to verify and adjust solutions that have been optimized during the design phase. Accordingly, this has made it possible to avoid time delays and errors, which otherwise would have affected the design time.

Competences from the pilot plant have contributed with the dimensioning of the installation unit. Frameworks and drawings of air and gas supply at the gas IR-dryer have been adjusted accordingly for this facility.

To be able to collect important information during the pilot operation, the gas IR-dryer will be prepared from the beginning and later equipped with thermal sensors. This will enable collection of important data for the engineering in the on-going efforts to optimize the emitters.

4. Results and discussion

The project group has carried out a complete design work of a gas IR-dryer consisting of four units, named emitters. The work also includes manufacturing of a gas IR-dryer prototype to make sure that ideas and product match. It is now possible to manufacture a gas IR-dryer for running trials and test functionality under realistic conditions.

To be able to implement the design work, it has been important to get an overview of earlier literature and studies about IR-technologies used in the paper industry. A problem has been the source of old information compared with available selection of materials. Another aspects are environmental issues.

This project is about optimization of the drying process through increased power, optimization of radiation wavelength and improvements of methods such as physical position of the dryer to have an efficient transfer of the radiation, avoid contamination of the burners and an efficient maintenance of the emitters.

The gas IR-dryer consists of modular units, named emitters that can be installed to cover the full width of any paper machine. The pilot dryer carries four emitters to cover the width of the pilot coater. A trial and evaluation will be conducted in a Swedish pilot-coating machine in the spring of 2013. During the pilot-operation, different pilot performances will be analyzed.

4.1 Emitter

The emitter dimensions are 800mm in MD (machine direction) and 150mm CD (cross direction), Figure 1. The CD measure is originally based on the setup of the head box slice openings. It is an average size to cover different width of paper machines. The dimension of the burner 200x150 mm is a manageable size and the emitter MD dimension is a result of this. Several emitters are installed side by side in a frame. The frame constitutes the complete gas IR-dryer, which will cover the full width of the paper machine. More than one frame can be installed in sequence or in other places of the paper-machine when so demanded.

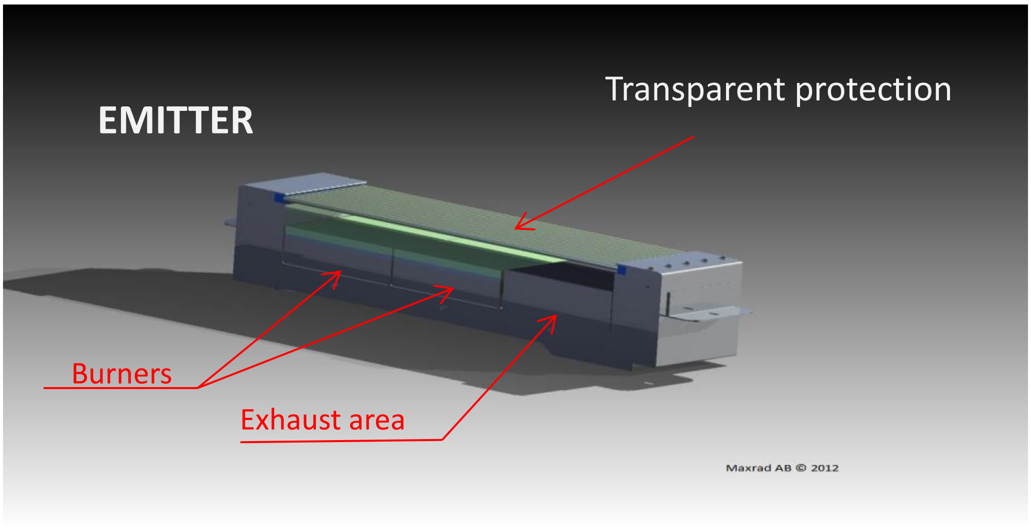


Figure 1. Emitter.

The burners, contained in the emitter, have an input power of approximately 1400kW/m^2. Expected radiant efficiency is 60-75%. The different methods of recycling exhausted gases contribute to the radiation output by being partly absorbed in a high emissive filter in the emitter and thereafter radiated back to the sheet. It is also the intention to use the remaining heat from the exhaust to pre-heat the combustion air, which will contribute to greater efficiency rates, Figure 2.

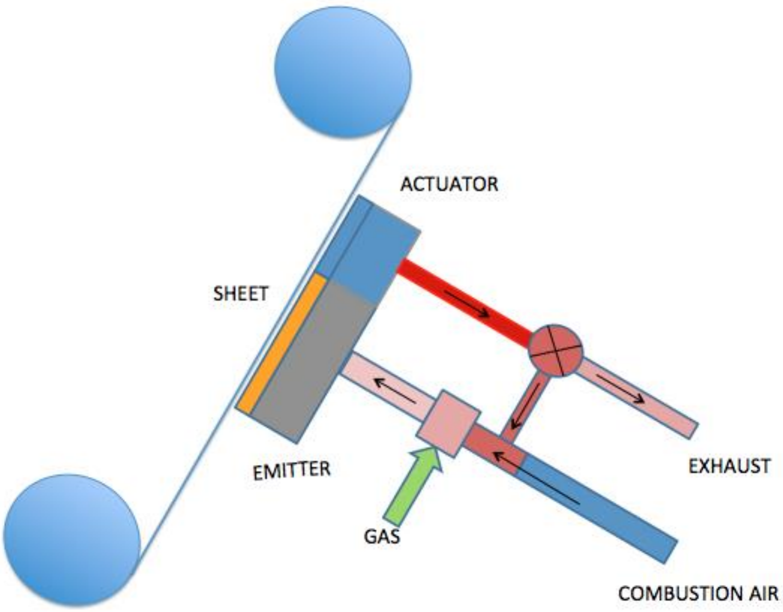


Figure 2. Recycling of exhaust for preheating of the fuel gas.

A transparent shield protects the burners. It allows the dryer to operate very close to the sheet, which improves the drying. The shield also protects the burner surface from being contaminated from coat splashing during production and sprayed of water when cleaning the dryer. Each emitter is individually removable and easy to service.

The drying energy load has to be calculated individually for each installation depending on actual parameters of the application.

To reach an optimal result of physical performance from an emitter, new materials are necessary. New, high emissive materials, durable at high temperatures, can provide considerable power output. Drying paper or coatings on paper, in a machine, producing various qualities at high speeds, requires high demands on a drying system. Installation of conventional gas IR-dryers need severe space in a paper machine, which most often is space limited, to compensate for low power density and lack of suitable radiation wavelength. The priority for a new dryer *was* to increase power density to a level where efficient drying can be accomplished in a limited installation.

The material for the burner is manufactured as a cellular structure, which stabilizes the combustion. Compared to conventional burners, the flame does not burn freely or at the surface. The flame is stabilized in a porous structure and the material fills the requirements of high temperature and thermo shock resistance in addition to having a long lifetime.

The design of the emitter can withstand high temperature using selected materials and keep a cool temperature of other parts that otherwise could be exposed to high temperatures. A trial with the burner material confirms the high radiant flux as a result of the combustion characteristics. The wavelength of the radiation is set to where the receiving paper products will absorb at a maximal level. Thanks to the cooled shield of the emitter, the distance to the paper web is narrower than before which improves the drying result. The emitter dimensions are minimized in order to fit into narrow machine spaces.

4.1.1 Distance to the paper sheet

There is an advantage to position the emitter as close as possible to the paper sheet, Figure 3.

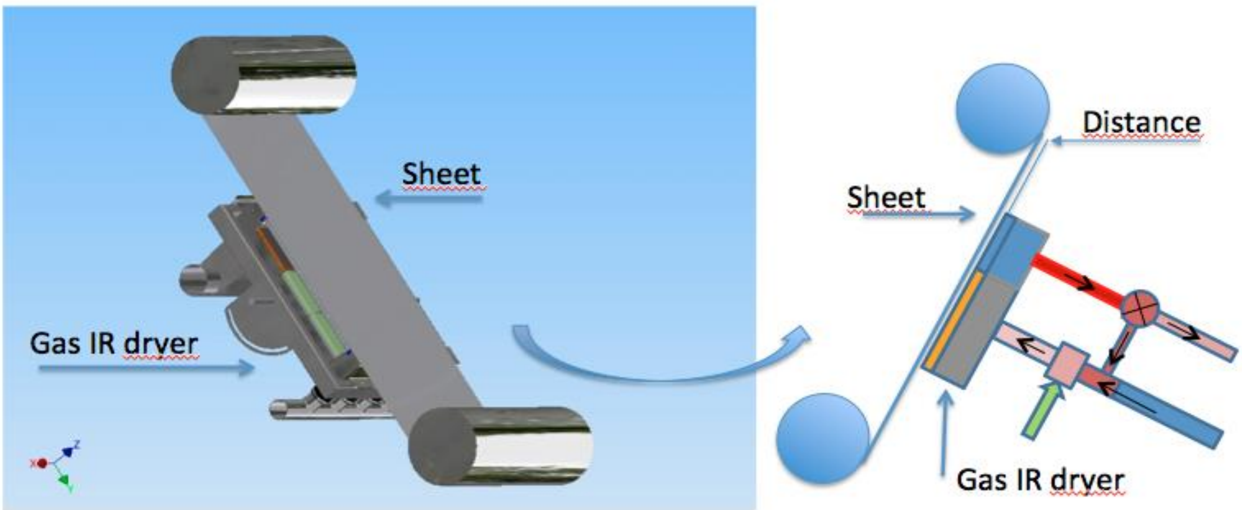


Figure 3. The emitter’s distance to the paper sheet

The prerequisites are to gain efficiency since radiation intensity is inversely proportional to the square of distance from the source, Figure 4 (6)

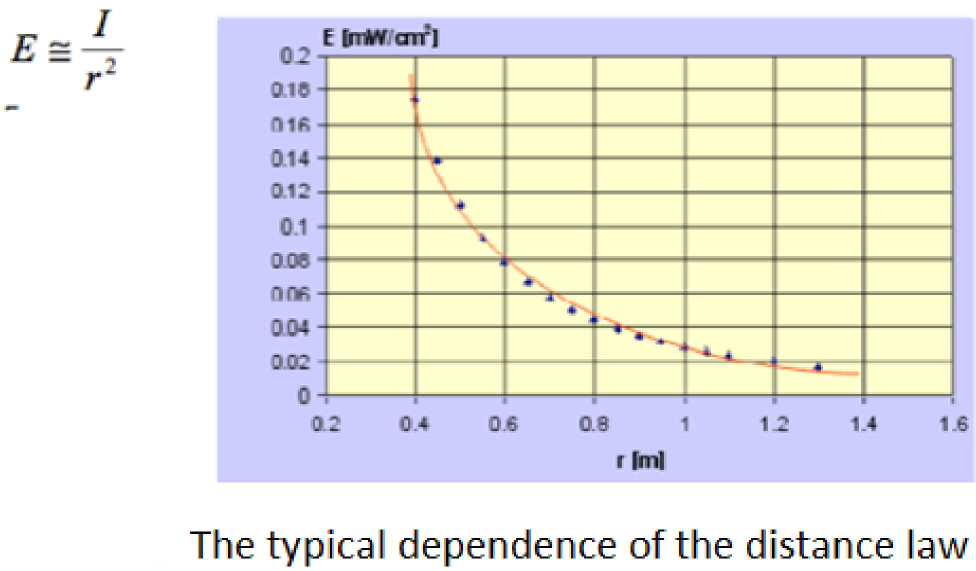


Figure 4. Illustration of the inverse square law, (6).

Considering that the sheet is exposed to the dryer for just a few milliseconds, and in this time the drying process has to get started, it is clear that the dryer has to utilize every possibility to maximal energy transfer into the sheet. Conventional gas IR-dryers are face open towards the sheet and have to operate from a distance and therefore loose efficiency.

4.1.2 The impact of burner temperature

The need for high burner temperature to reach the desired power and wavelength, respectively, requires the development of new materials and this has also been crucial task for reaching the aim of the project.

The explanation for the impact of burner temperature can be found in the combination of three laws, namely Plank's radiation law, Wien's displacement law and Boltzmann's law. Electromagnetic radiation emitted from a surface with the temperature "T" moves the radiation maximum to shorter wavelengths with higher temperature of the emitting surface. λ_{max} * T =2,8979 * 10-3(mK), where λ_{max} is the wavelength of maximum emission and T is the temperature, in Kelvin, of the emissive surface. On the other hand, the radiation emitted by a black body can be described as $E = \sigma^* T^4$, where σ is the Boltzmann constant (= 5.6697 10-8 [W/m^2K^4]). But a non-black body's radiation is reduced with radiation level (ε <1), $E = \varepsilon^* \Sigma^* T^4$. Assuming that the rate of emission of the temperature range is independent from the temperature, the equation becomes simpler, $E \approx T^4$. The emitted intensity of the radiation will then only be dependent on the burner temperature. To make it more understandable, this will give six times greater relative change in radiant intensity at a temperature of 1400 °C [=6] compared to a temperature of 800°C [=1].

The material of a porous burner provides the right conditions with sufficient temperature for the drying result. New high emissive materials made from SiC, (silicon carbide) durable at high temperatures, can provide a considerable higher power output. Further consideration, when choosing the material, is temperature resistance and sustainability of the burner.

Figure 5. Burner at 1380°C with stable flameless combustion.

4.1.3 Protection of the burner

Surrounding structures near the radiant source must be protected from high temperature influence. It is crucial to reduce the impact, to create performance and reliability for long-term use. The transparent shield, positioned in front of the burner, eradicates the risk of fire when facing the paper sheet. It also hinders contamination of the burner surface. In similar situation*, o*pen face burners have to be maintained on a regular basis and are fire hazard, which requires extensive systems for fire appliance, Figure 6.

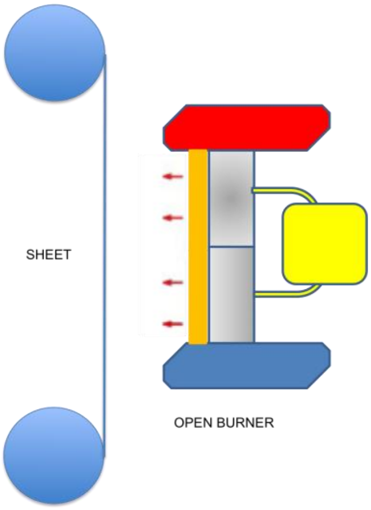


Figure 6. Principle with open burners to the sheet, at a distance, which limits the radiation efficiency.

4.1.4 Wavelength

Paper and cellulose fibers will not absorb any significant amounts of infra-red energy at wavelengths shorter than 1.35µm. Energy between 1,35µm and 2,0µm is weakly absorbed where radiation penetrates deep into the sheet and heats the interior effectively. At wavelengths greater than 2.0 µm, absorption in the surface is high and the surface heats up fast with a risk of overheating. The peak wavelength for the new dryer is aimed for 1.5-1.75 µm, which is the optimal wavelength for drying of cellulose fiber, Figure 7. Conventional gas infra systems generate wavelengths of 2.2 - 2.5µm and need accurate temperature control of the surface to avoid overheating.

Compared to conventional products, gas- or electric, the new gas IR dryer will perform better due to the optimized wavelength at a higher power density.

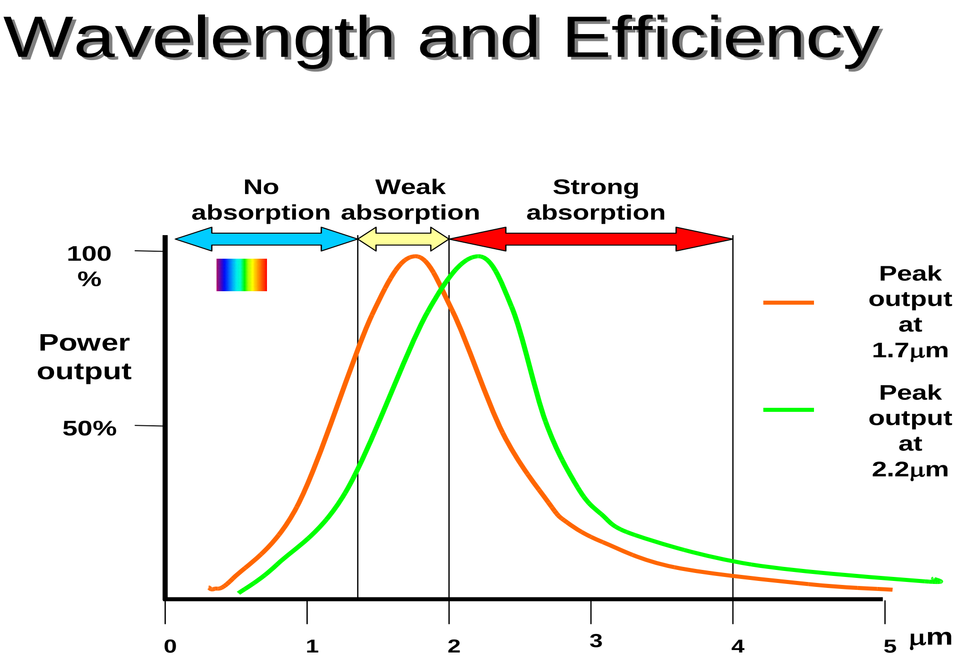


Figure 7. Optimal radiation wavelength for weak absorption in cellulose fiber.

4.2 Maintenance and Service

The emitter is designed to be easily replaced. It has been important to design the guides that allow removal and re-installation, without the mutual tolerance between the units. This provides a consistent performance of the unit after maintenance. The time required has been minimized due to a strong demand from the industry in this difficult service area, Figure 8.

The gas IR-dryer offers a unique possibility of reliability and gives protection from the corrosive environment inside the paper machine and therefore less need of maintenance.

Figure 8. Example of service area between press and drying section.

4.3 Progress of project and product

The new dryer is a result of a long experience of drying in paper- and board machines and a consequence of bringing people into the project from completely different professional backgrounds. It has been very rewarding to work with persons that have an impartial view on this particular technology. New opinions have been of great value and thus the basic idea for a new dryer was established.

New technology has a certain time to reach the market. The project has started to contact plants during the development of the gas IR-dryer prototype, which resulted in the possibility to conduct trials in a Swedish pilot coating machine making it possible to evaluate the performance of the prototype. This is an important opportunity for the commercialisation of the new dryer.

5. Conclusions

In this project, a new gas IR-dryer was developed and designed to provide high radiation power at an optimal wavelength for improved drying rates.

- The project has been successful in reaching its aim.
- A gas IR-dryer will be manufactured and then used for a pilot trial. However, the main reason has been to ensure the choices of design and the possible output of the developed dryer.
- The selection of porous material has made it possible to obtain high temperature power, optimal wavelength density of efficiency and optimal wavelength, to radiate deep into the paper respectively.
- The flexible and minimalistic design of the gas IR-dryer enables other position of the dryer in the paper machine, which positively affect the outcome of the capacity.
- The design provides low risk of fire if paper fall on the dryer and hinders contamination of burners.
- Easy maintenance and service of the emitter or the entire gas IR-dryer.

6. Future work

The project has raised several new questions and needs to investigate:

- To run a pilot-operation to verify performance and functionality of the gas IR-dryer.
- The dryer is primarily to be installed in the paper industry, but there are several other markets for this dryer due to the capacity and safe performance.
- The drying capacity has to be calculated for each installation as this differs dependent on the application.
- Develop adopted electronic communication and control.
- Investigate different fuel gases.

7. Acknowledgements

I like to thank Energimyndigheten and SGC AB for the financial support of this project, and a special thanks to Anna-Karin Jannasch, responsible at SGC, who have been most helpful and supportive to give us the opportunity to accomplish this project.

I also thank Stig Nodin, Nodins Synergieffekt AB, for a very professional work as technical leader, and Kaj Andersson, Tonsberg Maskinteknik, for the engineering work. A special thanks to Leif Broberg, Brålanda Industrier AB, for good advice concerning manufacturing and for the prototype at their expense.

Thanks also to the Reference Group including Karin Nodin, Niclas Karlsson Tremcel AB, Peter Zienau and Stefan Swedhem Innovatum AB, for support and encouraging participation in the project.

8. Literature

1. Affärstidningen Näringsliv., SNL.5 2012, Liquid Natural Gas. www.naringsliv.se/tidningar/artiklar/?artID=1996&TB=savedValues&TB_iframe=true&height=600&width=880&modal=false

2. Arwidsson, E., 2009. Håfreströms bruk http://www.industrihistoriaivast.net/upload/Innovatum/IHV/Håfreströms%20bruk%20artikel.pdf

3. Edgar, R. F., 1987. Drying of paper coatings by infrared radiation. Infrared Engineering Ltd. PITA. Bury Lancashire

4. Gasföreningen., 2010. Energigaser bra för både jobb och miljö. Stockholm www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDwQFjAA&url=http%3A%2F%2Fwww.energigas.se%2FPublikationer%2F~%2Fmedia%2FFiles%2Fwww_energigas_se%2FPublikationer%2FInfomaterial%2FSysselsattning.ashx&ei=YLhjUaSmJua54ASJ_oCICg&usg=AFQjCNH9Q2TBwxHDLp2t7_RLPU4G2ZG1vQ&sig2=4zM-G4ht2qwq0Pife1RfdA

5. Gavelin, G. 1982. *Torkteknik för massa och papper-teori och ekonomi*. Markaryd: Bröderna Hansson Boktryckeri AB

6. LEPLA, Irradiance versus distance. Exploring the inverse square law. www.lepla.edu.pl/en/modules/Activities/m29/files/invsqr.pdf

7. Näslund, M., 2011. Energigasteknik. Svenskt Gastekniskt Center AB. Malmö www.sgc.se/ckfinder/userfiles/files/Energigasteknik.pdf

8. Persson, P-A., 1992. Rapport SGC 025, Papperstorkning med gas-IR. Svenskt Gastekniskt Center AB. Malmö www.sgc.se/ckfinder/userfiles/files/SGC025.pdf

9. Petterson, M., & Stenström, S., 2000. Experimental evaluation of electrical dryers. *2000 TAPPI JOURNAL PEER REVIEWED PAPER*. www.gaspaperdryer.org/GasIRPaper/download/TAPPI%20IR%20Elec%20Dryers.pdf

10. PWC,. 2013. 16th Annual findings in the forest, paper & packaging industry. www.pwc.com/gx/en/ceo-survey/2013/pdf/pwc-global-ceo-survey-2013-forest-paper-packaging-key-findings.pdf

9771102737101