Direct Gas Fired Cylinder Heater for Paper Drying

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The goal of the project was to find out if paper drying could reasonably be done with direct gas fired cylinders. The preliminary study contained the collection of basic data; literature, patents, experiences from pilot plants. The technical analysis of the preliminary study contained a rough calculation of heat transfer with a computer program which was made as a part of the preliminary study. Direct fired system was compared to steam heating.

General tendency in paper production is that various paper properties have to be improved. Their variation in the cross direction and machine direction has to be reduced. Improved runnability with fewer breaks and fewer stops and an overall energy efficiency in the integrated mill are a part of these objectives. With the natural limit on steam pressure to be used in the drying cylinders, increase of speed and width of the machine, one possibility to reach higher surface temperatures and higher drying efficiency could be direct gas fired cylinders.

With a patent and literature search it was found 9 patents or patent applications of direct gas fired cylinders. The oldest patent was from year 1932.

Around 1988, a first prototype of a direct fired system which uses hot air impingement on the inside of the shell was installed for paper industry.

By reason of the high heat transfer rates attainable, there is a possibility for reduction in the number of drying cylinders. For example, where 40 or 50 steam heated drying cylinders are now required in paper making, the number may be reduced to 15 or 20 with a corresponding decrease in required floor space.

There are no significant losses when gas and combustion air are transported to the drying cylinders. The direct fired system can be between 75 % and 80 % efficient in the transfer of energy to the water or paper. If the exhaust gases are used in the pocket ventilation system of the paper machine, the efficiency rises to approximately 95 %. Up to 80 % of the energy content of the fuel can be used as heat or electricity when using the back-pressure power plant with steam heated drying cylinders.

As a result from the preliminary study it can be stated that gas–fired system offers an interesting possibility to reach higher surface temperatures and better drying efficiency compared to steam heated cylinders.
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PREFACE

February 1991 Nordic Gas Technology Center (NGC) ordered from Jamcon Oy a preliminary study concerning direct fired paper dryer using natural gas.

Technology Development Centre of Finland (TEKES) financed the study concerning information services.

Thomas Carlqvist and Ingemar Gunnarsson have been the contact persons of NGC. Oy Valmet Ab:s representative for the coordinator group was Jouko Yli-kauppila. The contact persons of TEKES were Kari Kaila and Christine Hagström-Näsi.

Preliminary study contains the collection of basic data; literature, patent analysis, experiences from pilot plants. Preliminary study's technical analysis contains a rough calculation of heat transfer with a computer program which was made as a part of the preliminary study.

2
BACKGROUND/1/

In any section of the paper machine, the objectives are to increase efficiency as well as quality and reduce costs, while following the general trends of increasing speed and width of the machine. Various paper properties have to be improved. Their variation in the cross direction and machine direction has to be reduced, even within narrow local regions of the web. Improved runnability with fewer breaks and fewer stops and an overall energy efficiency in the integrated mill are a part of these objectives.

With the natural limit on steam pressure to be used in the drying cylinders because of shell thickness, the search for higher surface temperatures led to gas-fired cylinders. Around 1988, a first prototype for paper industry was installed with hot air impingement on the inside of the shell.
After pressing, the residual water in the sheet must be removed by evaporation in the dryer section of the paper machine. The evaporation requires a large amount of thermal energy which is normally supplied in the form of steam. The dryer section is typically the largest energy consumer in the paper machine complex. The transfer of thermal energy from steam to the paper web requires considerable heat transfer surface. In most cases, the dryer section is physically the largest part of the paper machine. In spite of this, the dryer section often receives the least attention by the papermaker. There are often many opportunities to improve the paper making operation in the dryer section.

The purpose of the dryer section is to take the relatively wet sheet from the press section, containing 60 to 70 percent moisture, and remove additional water until the desired final moisture level is achieved, typically 4 to 8 %.

There is a wide variety of drying equipment used in the paper industry. However, the use of steam–heated cylinders is the most common method used to dry paper. Dryer felts or fabrics are commonly used to hold the sheet against the cylinder surface except in the case of heavy paperboard. A modification to heated-cylinder drying has been the shift to a draw-free sheet transfer between dryer cylinders through the application of a single dryer felt which maintains contact with the sheet. This change results in only one side of the sheet being in contact with the drying cylinders while the other side of the sheet is in constant contact with the dryer felt. The large Yankee dryer cylinder is used to provide one-side heating for lightweight paper products. This single-side cylinder heating coupled with direct impingement of high–velocity hot air is the traditional way to dry tissue and toweling. More recently, through-air drying, where air is pushed or pulled through a permeable web, has been used in the drying of tissue, toweling, filter papers, and nonwovens. In contrast, the airborne dryer uses an air jet to assist the transport of the sheet as well as to control the heat and mass transfer. Radiant and dielectric heating are occasionally used for supplemental heating. Press drying, that is, exposing the sheet to high temperatures (over 100 °C) while pressure is applied for short intervals in a hot nip, has been proposed for the drying of high–yield pulps containing very stiff fibers.

Typically a dryer section of a paper machine contains 60 – 140 drying cylinders.
Fig. 1. shows a typical cylinder dryer section.

![Diagram of a typical cylinder dryer section.](image)

Fig. 1. Typical dryer configuration/2/.

3.2
Objectives of the dryer section/2/

The objectives of the dryer section can be summarized as follows.

1. The dryers must efficiently evaporate water with the least amount of drying equipment. Drying equipment is large and expensive. The dryer section design must provide high evaporation rates to minimize the equipment requirements. This must be done within the constraints of the paper grade. For example, high evaporation rates on some grades will produce poor sheet quality.

2. The evaporation must take place in a manner that will produce a high-quality sheet. The uniformity of evaporation in the cross-machine direction is the most critical parameter. Any variation in the cross-machine evaporation characteristics will produce an undesirable variation in the final sheet moisture profile. Other properties that can be affected are the sheet surface characteristics, cockle, curl and tensile properties.

3. The dryer section and auxiliary equipment must be designed to minimize the energy usage. A good target is to use 2960 kJ/kg water evaporated. There are many machines that use much more energy than this amount. The design of the systems that support the drying operation, such as steam and air handling systems, provide the main influence of energy consumption.
4.
The dryer section must be designed to support a high overall paper machine efficiency. Dryer section breaks are often one of the main contributors to lost production time on the paper machine. This problem becomes more of a concern at the high modern paper machine operating speeds.

3.3
Conventional steam-heated drying cylinder

A typical steam-heated drying cylinder is shown in fig. 2.

![Fig. 2. A typical drying cylinder.](image)

The wet paper from the press section is passed over a series of steam heated cylinders. The cylinders are typically 1.2, 1.5 or 1.8 m in diameter. Modern machines most commonly use 1.8 m cylinders. Steam is fed into the cylinders and the heat from the steam is transferred through the cast iron shell and into the paper web. Steam pressure can vary from sub-atmospheric pressure to 1000 kPa depending on the paper grade. Synthetic fabrics are used to press the sheet tight against the cylinder. This improves the heat transfer by providing better contact between the paper web and the drying cylinder. It is in the open draw between top and bottom dryers where the majority of the evaporation takes place. The evaporated water is carried away by ventilation air./2/

A condensate layer is formed inside the dryers as the steam condenses. This condensate layer has a major influence on drying efficiency and uniformity. One of the major purposes of the steam and condensate system is to efficiently remove the condensate from the rotating dryers. A piece of equipment called a dryer syphon is used to remove the condensate from the dryer.
Heat power demand for one steam cylinder is approximately 300 kW. So the total power demand for the drying part is 18 – 30 MW.

Investment costs for one massiv steam heated cylinder are approximately 1 milj.FIM. So the total cylinder costs for the whole paper machine are typically 60 – 140 milj.FIM. Investment costs for the steam and condensation system of a paper machine are roughly 25 milj.FIM.

The traditional steam system sets a limit for the running speed of the paper machine (and also for the production capacity); 1500 m/min.
4 DIRECT GAS FIRED CYLINDER HEATER FOR PAPER DRYING

4.1 Principle of direct heating

Direct fired cylinder heating for paper drying is a system where a product is brought over an outer surface of a cylinder format shell and inside the shell is brought gas and air or a mixture of gas and air which is burned inside the shell and hot exhaust gases are brought to a contact with the inside of the shell to transfer heat to the cylinder shell.

![Diagram of direct gas fired cylinder heater]

Fig. 3. Principle of direct gas fired cylinder heater.

4.2 Possible advantages

Some of the possible advantages with the direct fired system are listed below:

- surface temperatures can be controlled by each cylinder and also along the direction of the cylinder axle
- steam and condensate systems can be reduced or replaced totally
- condensation problems can be reduced or avoided totally
- lighter construction; running speed of the machine can be faster
- shorter drying part of the machine
- more efficient drying than with the traditional steam system
- lower investment and operation costs than with the traditional steam system
- production of different paper types with maximum speed
- easier to installate to old machines than the steam heated cylinders

The preliminary study contains analyses of the potential advantages of the direct fired system.
5 PATENT AND LITERATURE SURVEY

5.1 General

Following information files were investigated during the literature search:

- paperchem
- energy
- energie
- compendex
- world textiles
- textile technology digest
- chemical abstracts
- apilit

A separate patent search was done by a patent office. Eight patents concerning the subject were found.

In 5.1-5.10 there is a short description of the patents and applications which were found.


This patent was the oldest one which could be found. The invention is primarily for textile industry.

Fig. 4. Gas heated ironing machine/4/. 
A short description of the system/4/:

An ironing machine comprising an ironing cylinder and a cooperating ironing member, said cylinder being rotatable, a relatively stationary burner located within the cylinder and arranged to direct flame upon the cylinder wall at the cavity therein, and a single means for withdrawing products of combustion from a zone at the bottom of the cylinder cavity, said zone having a length equal to that of said cylinder cavity and said means being effective throughout the entire length of said zone.

In 5.4 there is a more detailed description of a patent from year 1961 which seems to be just the same type as this one.

5.3 Patent; Hot Oil Heating Company, USA: Tempered Turbulence Roll-Type Drier, Application December 2, 1955/5/

The invention relates broadly to an apparatus for securing uniformity in temperature on cylindrical roll surfaces and more particularly to a method and apparatus for obtaining uniform temperature conditions on roll driers.

It has long been held that an evaporating liquid or condensing vapor because of the latent heat between the two phases, provided the best means of heat transfer because the heat transfer medium remains at a constant temperature. In the simplest of apparatus this is infallible, but in instances where high production and accurate control of temperature and heat transfer are demanded in the more complex processes, such as drying paper, chemicals and textiles that tenet has many disadvantages.

The invention provides an improvement thereupon in which heat transfer media are circulated around inside the rolls in a controlled manner to apply heat thereto or to cool by removing heat therefrom. The heat transfer media are usually liquid although they may be gas or superheated vapor and the heat transfer is that of sensible heat rather than latent heat of evaporation or condensation; however, with modifications this invention can be used with evaporating liquid or condensing vapor.

Since roll driers and Yankee driers are usually carried and revolve on journals and bearings at their axes, the practicable points of inlet and outlet are via hollow journals or shafts fitted with rotary joints or seals. To effect the highest efficiency of such apparatus it must be completely filled with whatever heat transfer medium is being used. In the case of steam or other vapors this creates a problem because of air or insoluble gases that can become trapped within the roll. In the case of a condensing vapor the condensate must be removed as rapidly as it is formed which often requires considerable complicated apparatus to perform the scavenging and condensate return operation. With the general availability of suitable liquid heat transfer media that do not vaporize and hence do not change phase during heating and cooling even at atmospheric pressure and at temperatures as high as 343 °C which is equal in temperature to more than 13.8 Mpa saturated steam pressure, it is much simpler, cheaper and more
efficient to heat or cool such apparatus (driers) with liquid heat transfer media, because said heating or cooling can be accomplished with very little pressure on the system, often less than 103 kPa on the user (drier), because the only pressure that is required is that necessary to circulate the heat transfer medium through the system.

Maintenance is much less because many such heat transfer media are non-corrosive, whereas many vapors are. Furthermore, all heat is sensible heat (no latent heat of vaporization or condensation is involved) and hence direct temperature sensing instruments and controls simplify and greatly increase the accuracy of temperature control and heat transfer.

Fig. 5 is a longitudinal vertical sectional view through one form of roll embodying the invention and showing certain of the parts in elevation and illustrating one method of conducting and returning heat transfer medium through one end of the roll.

Fig. 5. Temperature turbulence roll-type drier/5/.

Fig. 6. Transverse vertical sectional view taken on line 2–2 of fig. 1.
Fig. 7. Fragmentary and elevational view of the embodiment of the invention shown in fig. 5, partially broken away and shown in section.

Fig. 8. Longitudinal sectional view on a reduced scale of a shorter face drier roll with the internal distributor tube cantilever supported from the rotary joint with the end of the distributor tube stopped or plugged, the distributor tube being partially broken away and shown in section and certain of the parts being shown in elevation.

One of the further advantages of the roll construction of the invention resides in fact that it may be used without structural change for any duty within the range of minus 60 °C to plus 343 °C by merely changing the heat transfer medium. For example, this wide range can be obtained from only three heat transfer media and the apparatus operating at a pressure of less than 103 kPa. Methylenechloride can be used for temperatures from minus 60 °C to plus 38 °C at atmospheric pressure. A light turbine quality oil can be used for temperatures to 149 °C, and a heavier turbine quality oil can be used to 343 °C, both at atmospheric pressure. Thus the only pressure on the apparatus is that required to create turbulence and flow the heat transfer medium immediately through the roll.
This invention relates to methods of an apparatus for the internal heating of hollow cylinders.

Hollow cylinders in the form of drums, rollers and the like have for many years been used in many industries with heat applied interiorly thereof as by steam and other heating mediums. In some instances it has been proposed to place within the cylinder burners and to burn fuel within the cylinder for heat transfer to the interior surface. Where fuel has been burned inside the cylinder, the heat transfer rates have been relatively low because of several factors. First, there is inherently present adjacent the inner surface of the cylinder relatively dead air which in itself forms the principal heat insulator and reduces the rate of heat transfer. The withdrawal of the spent products of combustion represents a further problem and in the past has produced eddy currents and other flow of products of combustion in directions away from the interior surface of the cylinder.

In accordance with the present invention, high rates of heat transfer to the interior surface of hollow cylinders have been attained, transfer rates as high as 94.5 kW/m² of said cylindrical surface. Such high rates of heat transfer have been accomplished by eliminating substantially entirely the dead air space adjacent the inner curved surface, the avoidance of any tendency of the flame and hot products of combustion to move away from the interior surface of the cylinder, and by the attainment of unexpectedly high efficiency in the convection transfer of heat from the gases to the cylinder wall.

In carrying out the invention in one form thereof, a mixture of fuel and air is directed at high velocity at an angle to the interior surface and in such angular relation that as the pre-mixed fuel is burned, there are developed tangential forces from the expanding gases and products of combustion which maintain them against the concave surface of the cylinder. The gases move along the curved surface of the cylinder in high-speed turbulent flow. By reason of the high-speed flow and the constantly changing area wiped by the gases, any dead air space is eliminated to such degree that its effect on heat transfer is inconsequential. Further to increase the attainable rates of heat transfer, the cylinder is rotated so that its inner surface moves in counterflow with the rapidly flowing products of combustion to produce turbulent flow adjacent the curved surface. Further to maintain the high-speed curved path of the hot gases, there is provided an exhaust manifold having an inlet means spaced lengthwise of the roll and under substantial negative pressure. In this manner there are withdrawn through the exhaust manifold the gases while they are disposed closely against the interior surface of the hollow cylinder.

The cylinder itself is closed at its ends, and means are provided for relative adjustment of the locations of the exhaust manifold and burner so that the angular spacing may be varied while maintaining the flow of gases in close proximity with the curved surface of the cylinder. Such spacing is varied for different rates of flow of pre-mixed fuel and also for controlling the area of the concave surface used for transfer of heat to the external load. In this manner
there may be achieved optimum conditions of operation in terms of efficiency and/or desired high rates of transfer.

Fig. 9. An isometric view of an embodiment of the invention with supporting parts omitted.

Fig. 10. A sectional view of the cylinder-heating arrangement of fig. 9.
5.4.1
Application: Drying cylinder directly heated by gas, 1990/7/

A driven metal pre-drying cylinder is directly heated by a gas flame burner inside, directed at the area where the cloth is first fed on to the hot surface. 1 kWh per 1 kg of water evaporated is an average performance figure. This experimental design should avoid many sources of energy loss in a steam-heated cylinder. A prototype direct gas heated cylinder is installed in a Texunion factory, where productivity in predrying is up by 20-35 % depending on fabric type. The moderate cost is another fact which indicates that this heating method may be more widely adopted.
With the conventional process for heating the rollers of corrugated paper machines, in this case the grooved roller, the pressure roller and the drying assembly, heating is effected exclusively by steam. This source of heat calls for boilers, water treatment units, feed water and condenser water tanks. The purification process also requires at present an additional precipitation plant to separate out the chemicals which were added to the water. High-grade pumps and an extensive network of feed pipes are also essential to convey the steam to the corrugated paper machine. Steam traps and also condenser water pumps are necessary to return the condensed water. Seeing that a steam installation is subject to inspection at regular intervals by the boiler association, proper maintenance by a qualified boilerman is also required. Experience has shown that that the capital costs of such a steam installation are very high, so that not only the operating expenses, but also the costs of acquisition have an unfavourable effect on profitability.

The present invention now concerns a process for the heating of hollow cylindrical rollers of a corrugated paper machine and equipment for effecting the same, by means of which the task on which the invention is based is intended to be fulfilled simply and cheaply. The invention is presented in fig. 13.

Fig. 13. Equipment for the heating of hollow cylindrical rollers of a corrugated paper machine/8/.
The liquefied gas sprayed by the jet burner 6 into the combustion tube 11, and ignited therein, reaches a temperature of 1560 °C therein. The combustion tube 11 is raised to red heat. The radiator tube 10 is also heated by radiant energy from combustion tube 11, and gives rise to an even, radiant transmission of thermal energy to the more distant inner wall 1' of the roller 1, as is indicated by the arrows a. The heat absorbed by the inner wall 1' is propagated by conduction to the outer surface of the metallic roller 1 where, depending on the adjustment of the flow of the liquid, said outer surface reaches a temperature of about 100 °C to 250 °C.

The combustion gases passing through the combustion tube 11 are re-routed by the deflector 14 and flow back along the outside of the radiator tube 10, in the course of which, on their way to the heat shield 12, they meet the fresh air involved in the cooling of the bearings 2 and, with it leave the inner space 17 through the annular space 16. The size of the flame of the burner and, with it, the temperature of the roller, can be adjusted by means of the regulating valves 8, 9. The velocity of flow of the combustion gases and, as a result, the heat in the interior 17 of the roller 1, can be regulated by axial adjustment of the deflector 14 in the heat shield 13.
5.6 Application: Gas drying – profitability, investment, operation, 1979/9/

Drying cylinders heated via direct firing with gas are shown to incorporate considerable energy economy compared to steam-heated cylinders. E.g. in the manufacture of printing-writing paper using a dryer section having a nominal capacity of 2.5 t/hr, the reduction in energy consumption can run up to 8488 MWh/year. Investment costs are also slightly lower than for a system which uses steam-heated cylinders.

Fig. 14. Drying cylinders heated via direct firing with gas. a) principle of the system, b) regulation and safety device.
In some paper drying applications, it is desirable to supply or withdraw the hot air through one or both ends of the drum. In order to do this, an open-spoke head is used. The spokes are in direct contact with the flowing hot air. The temperature of the hot air changes very quickly at start-up or in the case of a break in the paper web. Due to the direct contact of the hot air with the spokes the spokes will change their temperature faster than the rest of the drum head assembly. Serious thermal stresses and deflections of the spokes result.

This invention prevents serious thermal stress and deflections in the spokes by interconnecting the drum and a rotatable shaft used to rotate the drum with a plurality of spokes which extend tangentially from the shaft to the drum.

Fig. 15 is a fragmentary perspective view illustrating the invention.

Fig. 15. Equipment for drying paper with hot gas.
In this invention the heating medium is a combustion product to which it has been mixed a certain amount of air for controlling the temperature. The combustion is usually made with a gas burner. The combustion product is delivered in both ends of the cylinder and further to ducts (4 in fig.16) which are located along the inside or outside surface of the cylinder. The heating medium is flowing in opposite directions in adjoining ducts. Heating medium then releases its heat to the outside surface of the cylinder.

The efficiency of the system is high, the surface temperature is even, the drying temperature is higher than with a steam-heated cylinder, the drying temperature can be regulated in a relatively large area.

Fig. 16. Drying cylinder heated with exhaust gases /11/
The gas fired paper dryer consists of four major components; a nozzle box assembly, recirculation fan, gas burner, and a dryer shell. The assembly of the nozzle boxes, the fan housing and the burner body is supported by two hollow shafts, which are fixed to the dryer frame. The dryer shell is supported by two bearings and can rotate freely without contacting the inside structure. The fan shaft is supported by two bearings inside the hollow shaft. The burner is inserted into the shaft of the nozzle box support at the opposite end of the dryer. The fan delivers hot air to the nozzle boxes where it impinges onto the inside surface of the dryer. The spent air returns to the centre plenum of the dryer mixing with combustion gases after which it is re-introduced to the nozzle boxes. Exhaust air is taken out of the dryer through exhaust ports at the end of the dryer.

Fig. 17. Direct fired cylinder heater /12/
5.9.1
Application; Linerboard application of the gas heated paper dryer

5.9.1.1
Product history

The gas heated paper dryer has been under development at ABB Flakt Ross Inc. throughout the 1980's. By replacing one or more regular steam dryers with it, papermakers can realise significant increases in paper drying capacity at a fraction of the capital cost and machine downtime of other alternatives.

The first gas heated paper dryer was built and tested in ABB Flakt Ross Inc. research laboratory between 1981 and 1984. It demonstrated the mechanical feasibility of the idea and the potential for increased drying.

The first mill prototype was installed at Flambeau Paper Corp in 1988 on the 1 machine, which makes a wide variety of grades and colours of fine paper. Testing on site demonstrated a potential production increase on the order of 15 % with a single roll, with no adverse effects on sheet quality whatsoever.

The current design of the gas heated paper dryer has the capacity to do the work of 4 to 6 regular steam dryers. Some key design parameters are shown in table 1.

Table 1. Gas heated paper dryer design parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum heat transfer rate</td>
<td>95,000 W/m²</td>
</tr>
<tr>
<td>Maximum internal air temperature</td>
<td>650 °C</td>
</tr>
<tr>
<td>Maximum dryer surface temperature</td>
<td>315 °C</td>
</tr>
<tr>
<td>Impingement air velocity</td>
<td>as in yankee hood</td>
</tr>
</tbody>
</table>

Two gas heated paper dryers have recently been installed on P.M. 5 at Paperboard Industries Corp. in Burnaby, British Columbia, Canada. Table 2 shows some key parameters of the machine. By replacing dryers 28 and 29 of the 53-cylinder dryer section, a 13.3 % increase in production was sought.

The installation is shown schematically in figure 18. Supply systems were housed on a mezzanine in the basement on the tending side, and exhaust systems on a mezzanine at the machine level, on the drive side. Each dryer employs a 2.64 MW (9 MBtu/hr) burner and a 150 kW (200 hp) recirculation fan inside the roll.
The installation included several additional features. New machine frame parts were installed to accommodate the new dryers. Maintenance was a key concern, and it was incorporated into the design of the recirculation bearings. For maximum efficiency, exhaust gases are recirculated back into the pocket ventilation system. The two dryers operate completely independently, from a common control panel. High temperature dryer fabrics were investigated and are employed.

Table 2. Paperboard P.M.5 parameters.

<table>
<thead>
<tr>
<th>Linerboard and corrugated medium</th>
<th>Escher Wyss roll former and Tampella long-nip press</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryers: 1.5 m (59&quot;) diameter and 4.72 m (186&quot;) face width</td>
<td>400 M.T.P.D. from 100 % recycled stock</td>
</tr>
</tbody>
</table>

5.9.1.2 Test methods

In order to directly measure the drying rate on the gas heated paper dryers, a large amount of additional instrumentation is included in the installation. The technique involves measurement of the heat transfer rate to the sheet via three independent methods, and also measurement of the contact heat transfer coefficient between the dryer shell and the sheet. This permits increased accuracy and close measurement of drying rate fluctuations.
The first method used to measure the heat transfer rate employs a control volume around the dryer as a whole (see figure 19). By accurately measuring all possible flows, a complete heat and mass balance for the system is obtained.

![Fig. 19. Heat transfer rate by overall heat and mass balance.](image)

An alternate method involves a control volume around a single nozzle box and its return gap within the cylinder (figure 20).

![Fig. 20. Control volume of calculation of heat flux by second method.](image)

The third method employs estimating the internal convective heat transfer coefficient using the ABB Flakt Ross Yankee hood technology (figure 21).
Fig. 21. Heat transfer rate from Yankee hood knowledge/13/.

The contact heat transfer coefficient is determined by measuring the sheet temperature in the draw and calculating its average temperature on the dryer shell from that. This technique has been previously employed by Karlsson.

Some of the key measurements require special instrumentation. The sheet temperature is measured using an infrared pyrometer in the dryer pocket, which includes a right-angle mirror, cooling water, and a compressed air lens–cleaning system. The dryer surface temperature is measured with a thermocouple embedded directly into the dryer shell, with the signal running through a slip ring on the end of the dryer. Both measurements are checked using a special handheld thermocouple assembly. The humidity of the exhaust is measured using the Flakt Ross High-Temperature Humidity Sensor System. All the information is forwarded directly onto an industrial computer for immediate compiling and calculation on site.

5.9.1.3 Current status/13/

Since the installation, a variety of events have occurred. All interconnections were completed and the system was started up while the machine was making paper. Some mechanical and instrumentation modifications were made to optimise the performance of the systems. Development of applicable high-temperature dryer fabrics continued, and the calibration of all research instrumentation was verified. The systems have now been in continuous operation for approximately four months.

In addition to these activities, some data has been collected with respect to contact heat transfer coefficients and drying rates at various temperature settings of the gas heated paper dryers. Preliminary indications point to type of furnish and freeness as significant factors.
By performing similar tests on the prototype installation at Flambeau Paper Corp., it was possible to develop distinct trends in contact heat transfer coefficient with basis weight and heat transfer rate (see figure 22). It is anticipated that this application will expand on these results.

Fig. 22. Trends at Flambeau Paper Corp. /13/
The application is made for treating a web type product, especially for drying it. The product is brought to a contact with a cylindrical surface. Gas and air or a mixture of gas and air is brought inside the cylinder. The mixture is burnt inside the cylinder and the hot exhaust gases are brought in contact with the inner surface of the cylinder to transfer heat to the cylinder. To get a reliable and simple construction many burner nozzles are located along the the cylinder axle inside the cylinder. The exhaust gases are directed radially against the inner surface of the cylinder.

Fig. 23 shows the principle and some details of the patent application.

Fig. 23. A solution and device to treat a web type product. 1) cylinder surface, 2) bearings, 3) gas, 4) air, 5) burner device, 6) flames, 7) suction nozzle, 8) exhaust pipe/14/.
6
SPECIAL TECHNICAL QUESTIONS

6.1
General

Typically paper producers are very conservative and every new application and
device must be carefully designed and tested before it can be taken into a larger
use. Successful pilot plant tests are essential for convincing the decision makers
that a system is reliable and economical.

Before it is reasonable to design and build any laboratory units or pilot plants
many technical questions should be answered. In parts 6.2–6.6 some of the most
interesting questions concerning the direct heated cylinder are studied.

6.2
Quality of the paper

6.2.1
General

Increasing the steam pressure inside the dryers increases the temperature.
However, there are practical limitations to the maximum pressure that can be
used. Most lightweight printing papers cannot use high pressures especially at the
wet end of the dryer section. It is not unusual to see pressures below atmosphere
in the wet end dryers of fine paper machines.

Some papers are harmed if the temperature of drying is too high. Glassine and
groundwood papers, for example, must not be dried at too high a temperature.
High temperatures are best suited to high-speed kraft papers and paperboard. It
is not unusual for linerboard machines to use 200–500 kPa pressures in the early
dryers and quickly graduate to pressures up to 1000 kPa. For paperboard too high
a temperature may cause ply separation on cylinder paper.

In general, paper should be raised in temperature slowly at the wet end of the
dryer section in order to prevent picking, blistering, blowing (in the case of
multi-cylinder boards), case hardening, cockling, and curling. Contact of cold
paper with a first dryer that is too hot will cause sticking and pulling of
excessive fiber from the sheet. Graduated drying is desired from the standpoint
of improved sizing. The paper should never be overdried, since this causes
brittleness and reduced strength. However, in order to get the center of the sheet
dry, the edges are often overdried. This not only results in extra steam
consumption, but also can result in a loss of sheet strength. A general rule is that
"the higher the printing requirements, the lower the wet end steam pressures and
the more gradual the increase in steam pressure".
Flakt Ross Inc. has installed a field prototype unit of a gas heated paper dryer at Flambeau Paper at Park Falls, Wisconsin. The number 1 paper machine at Flambeau produces number one uncoated opaque paper, high speed bond, mimeo, duplicator/savin and zero copy together with pocket folder and envelope paper. These different types of paper are made in basis weight ranges from 60 to 178 g/m². The colours range from bright and cream-white right through all the colours of the rainbow. The finishes include smooth, vellum and satin matte.

The mill has not been able to detect any problems as far as quality is concerned even with the highest temperatures. As far as can be determined, the sheet is not subjected to temperatures above 100 °C and is only against the hot metal less than one second.
6.3
Dryer fabric

6.3.1
General

To operate on a paper machine, a dryer fabric must meet certain requirements for strength and dimensional stability; it must operate at a specified permeability and it must be resistant to degradation under the ambient conditions of elevated temperatures and high humidities. Figures 24 and 25 show comparative data from laboratory tests. Synthetic fibers show a distinct improvement over cotton and wool fibers.\(^2\)

Overall, polyester has the best balance of characteristics for modern dryer clothing. However, its susceptibility to moist heat degradation sometimes decreases running time under extreme conditions; high cylinder temperatures and high humidity in the dryer pockets. Materials more resistant to hydrolysis, such as acrylic, polyamide, and aramid are being used in such cases.\(^2\)

![Fig. 24. Moist heat degradation of different yarns made from different materials. The breaking strengths are measured after exposure to relatively severe conditions of high temperature and high humidity in an autoclave for the time indicated. PPS = polyphenylene sulfide.](image1)

![Fig. 25. The dry heat degradation of yarns. The breaking strength of yarns is expressed here as a percentage of their initial strength after exposure to elevated temperatures in a forced draft, hot-air oven. That relative breaking strength is shown as a function of the time of exposure.](image2)
Usually dryer fabrics are made of polyester. Polyester can be used up to 240 °C which is a limit of hydrolysis—phenomenon; after this temperature molecule chains break. Polyester can soften already at 200 °C. With a special plastic based material the hydrolysis phenomenon can be avoided and the softening point can be lifted up to 265 °C./16/

Price of the polyester is about 250–300 FIM/m² and price for the special heat resistant dryer fabric about 340 FIM/m². Price for the dryer seam is about 1050 FIM/m for a polyester based fabric and 1350 FIM/m for a special fabric./16/

6.3.2
High temperature fabric tests at Flambeau/15/

A Brandon high temperature fabric was installed on the first top position on No. 1 paper machine at Flambeau Paper at Park Falls, Wisconsin. The high temperature fabric was a Uno–Plane HT SS™ specially designed high temperature resistant drying fabric. The permeability was 122 m³/minute, unit weight was 1010 g/m² and the caliper was 1.75 mm. The machine direction yarns are 0.38 mm high and 0.57 mm wide, rectangular PPS modified (Ryton) monofilament. The cross machine yarns are 0.6 mm circular PPS modified (Ryton) monofilament. The seam is a Flex–O–Pin woven spiral with a PEEK pindle and the breaking strength is 89 kg/cm.

By using this high temperature fabric Flambeau has been able to run the outside metal temperature on the gas heated paper dryer up to 260 °C. On the first trial the outside metal temperature was 225 °C and the steam pressure on the dryers before the size press was reduced from 331 kPa to 179 kPa. This indicated that a very large portion of the drying for the machine was taking place on the gas heated cylinder.
6.4 Construction of the drying cylinder

6.4.1 General

Usually drying cylinders are made of cast iron. The ends are inside or outside convex. Axles can be of the same cast as the ends or the axles can be made of steel especially if the width of the machine is big. The axles are dimensioned to last the load caused by the dryer fabric, cylinders own weight and the water load of the cylinder. Usually the drying cylinders are dimensioned to last 0.5–1.0 MPa (5–10 kp/cm²) water pressure./17/

Cylinders are equipped with a manhole for maintenance and inside installations./17/

Fig. 26. Typical steam–heated drying cylinder./17/

Drying cylinders can also be made of steel by welding. Steel structure is lighter because the required safety factors are smaller than with cast iron. Heat transfer coefficient of steel is also a little higher compared to cast iron./17/
6.4.2 Loads and dimensioning parameters/17/,/18/

The load of the bearings is calculated in situation when the cylinder is by half of its volume filled with water under operation circumstances.

The bearing reactions can be calculated from following equations:

\[
T_H = (cG_H + (b+1/2)(G_0 + G_V + P_{Hd}))/L
\]

\[
T_K = G_{KOK} - T_H
\]

\[
G_{KOK} = G_X + G_V + G_H + P_{H}
\]

Where
- \(G_{tok}\) is the total load (N)
- \(T_K\) is the bearing reaction of the operation side (N)
- \(T_H\) is the bearing reaction of the maintenance side (N)
- \(G_0\) is the gravity of the cylinder (N)
- \(G_V\) is the 50 % water load of the cylinder (N)
- \(G_H\) is the gravity of the gear (N)
- \(P_{H}\) is the pressure caused by the dryer cloth (N/mm)
- \(a, b, c, l\) and \(L\) are dimensions, see fig. 27.

Fig. 27. Calculation of the bearing loads.

The strenght calculations of the cylinder are made after the dimensioning standards of pressure vessels as follows:

SFS 2610/19/

The construction parts of the pressure vessel are dimensioned so that the allowed tension is not exceeded. The allowed tension \(\sigma_s\) of the cylinder jacket is calculated as follows:
\[ \delta_s = \delta_t / n, \]

where
\( \delta_t \) is the calculation strength \((N/m^2)\)
\( n \) is the safety factor

As the calculation strength it is used the smallest strength which causes the material break at the design temperature. The safety factor can be taken from the standard. For steam heated drying cylinder the safety factor is chosen by the dimensioning temperature which is the same as the highest steam temperature.

SFS 2611/20/
The jacket wall \( d_v \) can be calculated with the inside diameter of the cylinder as follows:

\[ d_v = pd_{sk}/(2\delta_s - p), \]

where
\( p \) is the dimensioning pressure \((N/m^2)\)
\( d_{sk} \) is the inside diameter of the cylinder \((m)\)
\( \delta_s \) is the allowed tension \((N/m^2)\)

The jacket wall \( d_v \) can be calculated with the outside diameter of the cylinder as follows:

\[ d_v = pd_{uk}/(2\delta_s + p) \]

The dimensioning pressure \( p \) \((N/m^2)\) is defined according to standard SFS 2610 paragraph 3.4 and it is the same as the highest allowable operation pressure.

The ends are calculated as straight covers according to standard 2616. Thickness of the circular covers is calculated as follows:

\[ d_e = 0.42d_{uk} \sqrt{p/\delta_s} \]

The extra thickness for the jacket and end have to be reserved so that the cylinder wall thickness is \( d_v + c_z \) and the ends thickness is \( d_e + c_p \). The extra thickness covers the possible corrosion and other wear caused by the operation. The extra thickness is taken from standard SFS 2610 paragraph 3.7.
6.4.3 Bearings and gaskets/18,19/

The cylinders are usually equipped with circular type roller bearings. Also cylindrical roller bearings are used. As the duration time for the bearings it is usually used 150,000 – 200,000 h. In calculations the high operation temperature must be noticed.

The difference between the operation and the standing temperature of the cylinder is big and the extension of the drying cylinder due to the temperature difference must be taken into consideration when designing of the bearings.

Bearings of the operation side are usually axially fixed. On the maintenance side it is needed separate bearing casing for the thermal extension.

The thermal extension can be calculated as follows/21/:

\[ l_2 = l_1(1 + \alpha (t_2 - t_1)), \]

where
\[ l_2 \] is the length of the cylinder after thermal extension
\[ l_1 \] is the length of the cylinder before the thermal extension
\[ t_2 \] is the end temperature, °C
\[ t_1 \] is the start temperature, °C
\[ \alpha \] is the thermal extension factor, 1/°C

For example for a gas fired drying cylinder the thermal extension can be as follows:

a) cast iron construction

\[ l_2 = 9000 \text{mm}(1 + 0.000009 \frac{1}{°C}(500-20)°C)) = 9039 \text{ mm} \]

b) steel construction

\[ l_2 = 9000 \text{mm}(1 + 0.000011 \frac{1}{°C}(500-20)°C)) = 9048 \text{ mm} \]

Oil lubrication is used for bearings which operate under high temperatures and also for big roller bearings which run with high rotation speeds.

O-rings can be used as axle gaskets. Usual rubber types can be used up to 150 °C but with special materials temperatures up to 300 °C can be reached.
6.5 Maintenance and safety aspects

6.5.1 General

Since dryer sections require use of high temperatures and pressures, they must be treated with caution. The nature of the dryers' function and required operating care make it important that they be given close attention in the mill safety program. The key to dryer safety is to keep operating personnel from getting into dangerous areas or unsafe positions, especially while the dryers are operating. If unsafe conditions exist, the dryers must be shut down until the condition is corrected.

Machine tenders and other mill personnel with work assignments in the dryer section must be given complete safety instructions and be on guard against potential hazards. They should be carefully instructed on the proper use of equipment and potential dangers of the steam and gas systems, high pressures and high temperatures associated with dryer operation. Also, adequate barriers, footwalks and signs should be installed at appropriate locations to protect and warn personnel of the potential hazards.

Preventive inspection and subsequent maintenance of the following will avert potentially hazardous situations for machine tenders and protect the dryer section from the possibility of serious damage.

Felts and felt seams should be inspected at least once a shift on high-speed machines, and during all clothing changes. Should a felt seam part, due to fatigue or wear, serious damage could occur.

6.5.2 Dryer warm-up procedure

The warm-up procedure that follows must be adhered to, to avoid excessive stress concentrations in the dryers due to large variations in temperature. Failure to follow this procedure can be dangerous to life and machinery. The controlled warm-up should be tailored to your operation.

6.5.3 Broke removal in dryers

When a person has been assigned to pull broke under the dryers, that person must notify the back tender that he or she is going under the dryers. An observer or assistant must constantly accompany the worker. In the event of a sheet break, upon hearing the break horn, the worker and assistant must get out from under the dryers immediately. As a back-up to the automatic break detectors, it is the responsibility of the backtender to locate the observer and the person under the dryers to see that they are clear.
6.5.4
Entrance into dryers/2/

Dryer cylinders are classified as unfired pressure vessels, in the same category as closed storage tanks, tank cars, and process vessels that have limited access openings for personnel. Dryers have to be entered for inspection, cleaning, repair and other functions associated with the dryer's operation (Fig. 803).

Some hazards that may be encountered upon entering a dryer are:
- lack of oxygen, causing asphyxiation
- accidental rotation of the dryer, because of poor lockout procedures
- electric shock from portable lights, tools or associated electrical equipment
- slipping and falling
- loose falling objects
- toxic vapors in fatal concentrations from welding
- heat stress
- burns from accidental opening of steam valves in a line not properly disconnected, blocked off, or locked out
- thermal burns from contact with hot water, hot shell, condensate or steam lines
- unprotected or improperly insulated hot water, condensate or steam lines
- poorly maintained manhole entrance with sharp edges and rust

6.5.5
Procedure in emergency situations/22/,/23/,/24/

6.5.5.1
General

By emergency situations it is meant a situation which have led or can lead to a situation where people are in real danger or material damages are evident. An example is a break of natural gas pipe line.

Another emergency situation is a situation where gas leakages have occurred into a closed cylinder and explosion hazard is obvious and the situation can't be controlled by normal operations and overhaul.

An emergency situation is not an event when the seams or the operation equipment have small losses of gas which can be handled by the operation personnel.

6.5.5.2
Gas leakage and gas fire

Fires in paper machine dryer sections are dangerous and difficult to fight. The use of water to put out or contain the fire can create a greater hazard to personnel and equipment than the fire.

To douse a hot dryer shell or head with cold water results in a sudden thermal shock that creates extremely high stress in the shell. The result may be shell failure or explosion.
A fine spray should be used, about the volume of a garden hose, NOT the full volume of the fire hose. The dryer cylinder must be rotating and the spray should be worked back and forth across the cylinder so the wetting is uniform.

Automatic sprinklers are also likely to be activated over hot dryers. A water temperature of 50 °C would not be too hot to prevent fire fighters from entering the area.

If the gas fire has already started it should always be extinguished by preventing the entrance of gas to the dryer by shutting the valves. The gas fire goes out when the pressure in the pipeline has reduced. The gas fire should not be attempted to extinguish unless it is extremely necessary. Uncontrolled gas leakage is always more dangerous than a controlled fire. In case of a gas fire it is most important to save the people in danger, separate the area and to cool the structures exposed to the fire.

If the gas is leaking in the cylinder the following procedure should be followed:

- the main shut-off valve is closed
- the burner air fan is left in operation to ventilate the cylinder
- people are moved away from the area
- an announcement is made to the responsible operator

Safety instructions for gas burners are defined in SFS standard 5123:E, Gas burners, control, regulating and flame safety devices.

6.5.6
Maintenance aspects from Paperboard Industries Corporation

In the first commercial installation at Paperboard Corporation in Burnaby, B.C. Canada two steam-heated dryers have been substituted by two gas heated dryers. The diameter of the existing steam-heated dryers on the Paperboard machines are 1.5 m. The gas heated paper dryers are 1.524 meters in diameter. The gears on these dryers were disconnected and the gas heated paper dryers were driven with the dryer fabrics. The circulation fans are direct driven with AC variable speed motors mounted at the rear of the machine. The burners are on the front side and the exhaust ports and the exhaust manifolds are on the back side of the paper machine so that they would not interfere with threading the tail. The fan bearings are of the split Cooper design and these bearings can be changed without removing the fan or the fan shaft from the gas heated paper dryer. A provision is also made for cooling air to be supplied to these bearings. The fan is equipped with a water pad and the heat flinger to prevent excess heat reaching the inside bearings.

Fig. 28 shows the method of removing the nozzle box assembly and fan, should this be necessary. These fans have been used in the steel industry for over forty years with temperatures up to 1100 °C. However, it was decided to make provision in the first commercial installation for removal of the innards of the gas heated paper dryer, should this be necessary.
The frame of the front side has been designed for easy removal and once the head on the dryer is removed, then the internal assembly including the fan, can be moved out into the front isle of the paper machine.

Fig. 28. Method of removing the nozzle box assembly and fan of the Flakt Ross Inc. application.
7
HEAT TRANSFER

7.1
Steam heated drying cylinders/2/

7.1.1
General

The drying process can be broken down into two basic components: a) the transfer of heat from steam into the paper web while on the drying cylinder; and b) the evaporation of water from the paper web into air during the draw between the cylinders. There are a number of variables which govern the process. These variables will be referred to as "Steam side variables" (heat transfer to the web) and "Air side variables" (evaporation of water from web).

7.1.2
Heat transfer

Heat is transferred from the steam through the dryer shell into the paper. As the paper web contacts the dryer surface, the dryer fabric presses the sheet against the dryer surface and improves the contact. The fabric also restricts the evaporation while the sheet is on the dryer. Therefore, while on the dryer, the sheet temperature rises as heat is transferred into the sheet and little evaporation takes place.

Figure 29 shows an exploded section of the dryer shell during the heat transfer phase of the drying cycle. Heat transfer into the sheet follows the basic heat transfer formula:

\[ Q = U \times A \times (T_s - T_p), \]

where
- \( Q \) is the rate of heat flow from steam to the paper (kJ/h)
- \( U \) is overall heat transfer coefficient which is a measure of the resistance to heat flow (kJ/h/m²°C)
- \( A \) is the dryer surface area in contact with the paper web (m²)
- \( T_s \) is steam temperature (°C)
- \( T_p \) is paper temperature (°C)

Fig. 29. Heat transfer with sheet on cylinder/2/.
The temperature of the paper \((T_p)\) is the variable which relates the heat transfer and evaporation process. Increasing the heat transfer will increase the paper temperature as it leaves the dryer which will increase the evaporation in the draw between the cylinders. Similarly, an efficient evaporation process will reduce the paper temperature in the draw between cylinders as the water evaporates. This results in a lower sheet temperature as the sheet comes back onto the next cylinder. the lower paper temperature improves heat transfer.

With a fixed number of dryers, the only two variables in the heat transfer equation that can be directly controlled are the saturated steam temperature \((T_s)\) and the overall heat transfer coefficient \((U)\).

As it was noticed in paragraph 6.2.1 increasing the steam pressure inside the dryers increases the temperature. Table 1 lists some typical grades and steam pressures used.

Table 1. Typical steam pressures used./2/

<table>
<thead>
<tr>
<th>Paper type</th>
<th>wet end (kPa)</th>
<th>maximum at dry end (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newsprint</td>
<td>-35 to 100</td>
<td>345 to 415</td>
</tr>
<tr>
<td>Woodfree Writing Papers</td>
<td>-35 to 0</td>
<td>345 to 520</td>
</tr>
<tr>
<td>Woodfree Copier Papers</td>
<td>-35 to 35</td>
<td>520 to 690</td>
</tr>
<tr>
<td>Lightweight Coated</td>
<td>-35 to 0</td>
<td>275 to 345</td>
</tr>
<tr>
<td>Supercalandered Groundwood</td>
<td>-35 to 0</td>
<td>275 to 345</td>
</tr>
<tr>
<td>Linerboard and Corrugating</td>
<td>200 to 520</td>
<td>1030</td>
</tr>
</tbody>
</table>

The overall heat transfer coefficient is a measure of the resistance to heat transfer. The resistances that make up the overall heat transfer coefficient are:

1. The condensate layer thickness and turbulence level. A condensate layer inside the dryer is created as the steam transfers heat and condenses. The layer creates a resistance to heat transfer. At higher speed, the resistance becomes greater as the layer becomes less turbulent. Keeping the condensate layer thin and turbulent will maximize the heat transfer. This is one of the most significant variables in the drying process.

2. The dryer metal thickness is a resistance to heat flow.

3. Any scale or fiber buildup on the outer surface of the dryers will cause a resistance to heat flow. Dryer surfaces should be kept clean.
4. A thin air film is trapped between the sheet and the dryer shell as the sheet comes onto the cylinder. The air film forms a very effective insulation layer. The purpose of the dryer fabric is to press the sheet against the shell and minimize the air film resistance.

5. The properties of the sheet affect the resistance to heat flow. The water content, thickness, surface roughness, porosity, etc., will influence the ability to transfer heat effectively.

6. Non-condensibles in the dryer drum reduce heat transfer. There can be air or other non-condensible gases in the steam supply to the dryers which can drastically reduce the heat transfer if they are allowed to accumulate.

7.1.3 Evaporation/2/

The heat that is transferred into the sheet while on the dryer cylinder is used to change the phase of water from a liquid to a vapor. For conventional drying conditions, the amount of heat required for this phase change is 2290 kJ/kg water evaporated. The majority of the evaporation takes place in the free draw between cylinders. The evaporation process is governed by a standard mass transfer equation.

Figure 30 shows an exploded view of the paper web in the draw between dryer cylinders. The evaporation from the sheet follows the basic mass transfer equation shown below:

\[
\text{EVAP} = K \times A \times (P_s - P_a),
\]

where

- **EVAP** is water evaporated from the sheet (kg water/h)
- **K** is mass transfer coefficient (a measure of the resistance presented by the air film on the surface of the sheet)
- **A** is evaporation area determined by the length of the draw (m²)
- **P_s** is vapor pressure of the water in the sheet (Pa)
- **P_a** is partial pressure of water vapor in air surrounding the sheet (Pa)

![Fig. 30. Evaporation in free draw.](image)
7.1.4
Influence of drying variables

There are a number of basic variables that determine the efficiency of a dryer section. These variables assume that the dryer geometry is fixed and the steam pressure is constant.

An estimate of the effects of the different drying variables on the overall dryer efficiency is given in table 2. The table is meant to give only a general indication of the overall impact of the different variables. It is difficult to give more exact estimates because of the interrelationship between the variables and the many different machine geometries and conditions.

Table 2. Effect of drying variables on drying efficiency.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>% INFLUENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensate removal</td>
<td>30</td>
</tr>
<tr>
<td>Furnish, Grade, and Sheet Properties</td>
<td>25</td>
</tr>
<tr>
<td>Dryer Fabric Design, Permeability and Tension</td>
<td>20</td>
</tr>
<tr>
<td>Pocket Ventilation</td>
<td>15</td>
</tr>
<tr>
<td>Hood and Dryer Air Systems</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
</tr>
</tbody>
</table>
7.2
Gas heated drying cylinders

7.2.1
General

There weren't any ready calculation methods available for the calculation of heat transfer of the gas fired drying cylinder. So a special computer program was made as a part of the preliminary study to calculate the heat transfer and energy balance of the gas fired drying cylinder. Input data, calculation procedure and results are presented in paragraphs 7.2.2-7.2.6.

The theory which was used in the calculations is based on the heat and mass transfer correlations for turbulent impinging jets.

The applications of impingement cooling or heating are wide ranging, and include processes such as drying of paper and textiles, tempering of glass, cooling of electronic components and turbine blades. In an industrial application, such as calender cooling or cooling of high energy density electronic components, where highly localized cooling is desired, a single jet (or a row of widely-spaced jets) is usually employed. However, when a larger surface is to be heated (or cooled), as in the case of an impingement dryer for newsprint, tissue or textiles, rows or arrays of jets are preferred. Slot and circular jets are the two most frequently-encountered configurations. Figure 31 shows some of the nozzle geometries and arrangements used in practice.

Fig. 31. Flow arrangements/26/.

For the computer program the arrangement type e) was chosen; arrays of jets with exhaust ports.
Some alternatives for the location of the nozzles are shown in figure 32.

![Alternative nozzle locations](image)

**Fig. 32. Alternatives to locate the burner nozzles.**

For the computer program the arrangement type c) was chosen; hexagonally located nozzles. The nozzles are located along the same surface area as the contact angle of the paper.

### 7.2.2 Geometrical optimization of the nozzle system

The goal for the construction of the nozzle system is to get the highest possible heat transfer coefficient per area with a specific burner output. There are three main dimensions which specify the geometry of the burner:

1. The diameter of the nozzle, $D$
2. The distance between the nozzles, $L_t$
3. The distance between the nozzle and the cylinder surface, $Z$

Martin has analyzed the heat transfer with circular nozzles and defined the geometrical dimensions corresponding to optimized heat transfer coefficient /27/:  

$$F_{\text{opt}} = \frac{\text{area of the nozzles}}{\text{heat transfer area}} = 0.0152$$

$$\frac{Z}{D}_{\text{opt}} = 5.43$$

The equations can also be presented in form:

$$D_{\text{opt}} = \frac{1}{5}Z$$

$$L_{t \text{opt}} = \frac{7}{5}Z$$

If the dimensions of the nozzles are not optimal the heat transfer coefficient gets smaller as follows:

$$\frac{\alpha}{\alpha_{\text{max}}} = \frac{G(S/Z,L_t/Z)}{(D_{\text{opt}}/Z,L_{t \text{opt}}/Z)}$$

The equation is illustrated in a figure 33.
If the dimensions of the nozzles are not optimal the heat transfer coefficient gets smaller as follows:

\[ \frac{\alpha}{\alpha_{\text{max}}} = \frac{G(S/Z, L/Z)}{(D_{\text{opt}}/Z, L_{\text{opt}}/Z)} \]

The equation is illustrated in a figure 33.

![Diagram for circular nozzles](image)

Fig. 33. Diagram for circular nozzles /27/.

In the middle of the diagram 33 the relation of \( \alpha/\alpha_{\text{max}} = 1 \) corresponding the output relation \( P/P_{\text{min}} = 1 \). The output relation \( P/P_{\text{min}} \) can be calculated as follows:

\[ P/P_{\text{min}} = (\alpha/\alpha_{\text{max}})^{0.2} \]

For example if the relation of heat transfer coefficients \( \alpha/\alpha_{\text{max}} = 0.85 \) the needed output \( P \) is approximately 2.1 times more than the minimum output.

When the nozzle geometry and dimensions are chosen the following aspects should be taken into consideration:

1. The distance between the nozzles should be big enough so that the amount of nozzles could be kept reasonable

2. The distance between the nozzles should be kept small enough to avoid the variations to the local heat transfer coefficient and to the heat flow which could cause longitudinal striping of paper.

3. The dimensionless distance of the nozzle from the cylinder surface \( H (=Z/D) \) must be under 12 so that the effect of \( H \) to Nusselt's number (and further to the heat transfer coefficient) is small.

When the nozzles are located hexagonally the amount of nozzles can be kept smaller than if they were located in lines or rows.
In figure 34 the amount of nozzles is shown as a function of the distance between the nozzles.

Fig. 34. The amount of nozzles as a function of the distance between the nozzles. Hexagonally located nozzles. Nozzle diameter 12 mm.
Computer program

The computer program which was made for the heat transfer calculations consists of one main program and 12 subprograms:

1. **GASDRY**
   Main program gasdry asks the needed input data, calls the subprograms, calculates the amount of convective heat transfer, the amount and temperature of exhaust gases, the amount of needed combustion gas and air, and the total efficiency.

2. **CNH2NTAD**

3. **CNH2NLAM**
   Subprogram calculates the air factor. Calculation is based on the tables presented in source /28/ pages 558–561 and 601–603.

4. **GASRAD**
   Subprogram calculates the amount of heat transfer by radiation to the cylinder surface. Calculation is based on the theory and tables presented in source /29/ pages 657–661.

5. **NGFGFLOW**
   Subprogram calculates the forced convective heat transfer to a heated surface with the jet impingement. Calculation is based on Martin's theory/27/.

6. **MAIRCON**
   Subprogram interpolates the heat conductivity of moist air from the information given in source /28/ pages 733, 753 and 755.

7. **AIRCON**
   Subprogram calculates the heat conductivity of dry air from the information given in source /28/ pages 434 and 435.

8. **HOYCON**
   Subprogram calculates the heat conductivity of the saturated steam with the equation shown in source /28/ page 755.

9. **DENAIR**
   Subprogram calculates the density of moist air with the equation shown in source /30/ pages 1–16.

10. **MAIRVIS**
    Subprogram calculates the viscosity of moist air with equations shown in source /31/ page 368.
11. VISAIR
Subprogram calculates the dynamic viscosity of dry air with an equation shown in source /28/ page 746.

12. VISHOY
Subprogram calculates the dynamic viscosity of water vapour with an equation shown in source /28/ page 746.

13. CAPAH
Subprogram calculates the heat capacity of the moist air.

Following variables are used as input for the program:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qk</td>
<td>drying effect, kW/m²</td>
</tr>
<tr>
<td>T2</td>
<td>temperature of the drying cylinder, °C</td>
</tr>
<tr>
<td>Tmax</td>
<td>maximum allowed construction temperature, °C</td>
</tr>
<tr>
<td>Ds</td>
<td>diameter of the nozzle, mm</td>
</tr>
</tbody>
</table>

Program gives following output:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qrad</td>
<td>amount of radiation heat transfer, %</td>
</tr>
<tr>
<td>Qkonv</td>
<td>amount of the convective heat transfer, %</td>
</tr>
<tr>
<td>lambda</td>
<td>air factor</td>
</tr>
<tr>
<td>mp</td>
<td>natural gas consumption, g/sm²</td>
</tr>
<tr>
<td>mi</td>
<td>combustion air consumption, g/sm²</td>
</tr>
<tr>
<td>un</td>
<td>gas velocity in the nozzle, m/s</td>
</tr>
<tr>
<td>n</td>
<td>amount of nozzles</td>
</tr>
<tr>
<td>Zn</td>
<td>distance of the nozzles from the surface, mm</td>
</tr>
<tr>
<td>Ld</td>
<td>distance between the nozzles, mm</td>
</tr>
<tr>
<td>T4</td>
<td>temperature of the exhaust gases, °C</td>
</tr>
<tr>
<td>ct</td>
<td>total efficiency of the drying, %</td>
</tr>
</tbody>
</table>
7.2.4
Calculation results

Some calculation results are shown in fig. 35 and 36 and tables 3–5.

Fig. 35. Drying efficiency (et) as a function of drying effect (Qk) with different cylinder temperatures (T2) when Tmax = 600 °C, Ds = 6 mm.

Table 3. Calculation results with different drying effects (Qk) when T2 = 200 °C, Tmax = 600 °C, Ds = 6 mm.

<table>
<thead>
<tr>
<th>Qk, kW/m²</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qrad (%)</td>
<td>3.7</td>
<td>1.9</td>
<td>1.2</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Qkonv (%)</td>
<td>96.3</td>
<td>98.1</td>
<td>98.8</td>
<td>99.1</td>
<td>99.3</td>
</tr>
<tr>
<td>lambda</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
</tr>
<tr>
<td>mp (g/sm²)</td>
<td>1.62</td>
<td>4.65</td>
<td>8.58</td>
<td>13.26</td>
<td>18.59</td>
</tr>
<tr>
<td>mi (g/sm²)</td>
<td>130</td>
<td>374</td>
<td>690</td>
<td>1067</td>
<td>1496</td>
</tr>
<tr>
<td>un (m/s)</td>
<td>21.2</td>
<td>61.2</td>
<td>113.1</td>
<td>174.8</td>
<td>245</td>
</tr>
<tr>
<td>n (pcs/m²)</td>
<td>546</td>
<td>546</td>
<td>546</td>
<td>546</td>
<td>546</td>
</tr>
<tr>
<td>Zn (mm)</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Ld (mm)</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Te (°C)</td>
<td>482</td>
<td>518</td>
<td>533</td>
<td>543</td>
<td>549</td>
</tr>
<tr>
<td>et (%)</td>
<td>24.7</td>
<td>17.2</td>
<td>14.0</td>
<td>12.1</td>
<td>10.8</td>
</tr>
</tbody>
</table>
Table 4. Calculation results with different temperatures of the drying cylinder (T2) when Qk = 50 kW/m², Tmax = 600 °C, Ds = 6 mm.

<table>
<thead>
<tr>
<th>T2, °C</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qrad (%)</td>
<td>1.6</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Qkonv (%)</td>
<td>98.4</td>
<td>98.4</td>
<td>98.5</td>
<td>98.6</td>
<td>98.7</td>
</tr>
<tr>
<td>lambda</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
</tr>
<tr>
<td>mp (g/sm²)</td>
<td>4.67</td>
<td>5.45</td>
<td>6.5</td>
<td>7.95</td>
<td>10.04</td>
</tr>
<tr>
<td>mi (g/sm²)</td>
<td>375</td>
<td>438</td>
<td>523</td>
<td>640</td>
<td>808</td>
</tr>
<tr>
<td>un (m/s)</td>
<td>61.4</td>
<td>71.8</td>
<td>85.7</td>
<td>104.8</td>
<td>132.3</td>
</tr>
<tr>
<td>n (pcs/m²)</td>
<td>346</td>
<td>546</td>
<td>546</td>
<td>546</td>
<td>546</td>
</tr>
<tr>
<td>Zn (mm)</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Ld (mm)</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Te (°C)</td>
<td>498</td>
<td>513</td>
<td>527</td>
<td>540</td>
<td>553</td>
</tr>
<tr>
<td>et (%)</td>
<td>21.4</td>
<td>18.4</td>
<td>15.4</td>
<td>12.6</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Fig. 36. Drying efficiency (et) as a function of nozzle diameter (Ds) and maximum structural temperature when Qk = 50 kW/m² and T2 = 200 °C.
Table 5. Calculation results with different nozzle diameters (Ds) when $Q_k = 50$ kW/m², $T_{max} = 600$ °C, and $T_2 = 200$ °C.

<table>
<thead>
<tr>
<th>Ds, mm</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{rad}$ (%)</td>
<td>0.8</td>
<td>1.5</td>
<td>1.9</td>
<td>2.3</td>
<td>2.7</td>
</tr>
<tr>
<td>$Q_{konv}$ (%)</td>
<td>99.2</td>
<td>98.5</td>
<td>98.1</td>
<td>97.7</td>
<td>97.3</td>
</tr>
<tr>
<td>lambda</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
<td>5.44</td>
</tr>
<tr>
<td>mp (g/sm²)</td>
<td>4.58</td>
<td>6.50</td>
<td>7.88</td>
<td>8.96</td>
<td>9.95</td>
</tr>
<tr>
<td>m (g/sm²)</td>
<td>369</td>
<td>523</td>
<td>634</td>
<td>721</td>
<td>801</td>
</tr>
<tr>
<td>u (m/s)</td>
<td>60.4</td>
<td>85.7</td>
<td>103.9</td>
<td>120.6</td>
<td>133.5</td>
</tr>
<tr>
<td>n (pcs/m²)</td>
<td>2183</td>
<td>546</td>
<td>243</td>
<td>134</td>
<td>86</td>
</tr>
<tr>
<td>Zn (mm)</td>
<td>16</td>
<td>33</td>
<td>49</td>
<td>65</td>
<td>81</td>
</tr>
<tr>
<td>Ld (mm)</td>
<td>23</td>
<td>46</td>
<td>69</td>
<td>93</td>
<td>116</td>
</tr>
<tr>
<td>$T_{eq}$ (°C)</td>
<td>496</td>
<td>527</td>
<td>540</td>
<td>547</td>
<td>552</td>
</tr>
<tr>
<td>et (%)</td>
<td>21.8</td>
<td>15.4</td>
<td>12.7</td>
<td>11.2</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 6. Calculation results with different maximum structural temperatures ($T_{max}$) when $Q_k = 50$ kW/m², $T_2 = 200$ °C and Ds = 6 mm.

<table>
<thead>
<tr>
<th>Tmax, oC</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{rad}$ (%)</td>
<td>1.5</td>
<td>2.4</td>
<td>3.7</td>
<td>5.4</td>
<td>7.4</td>
</tr>
<tr>
<td>$Q_{konv}$ (%)</td>
<td>98.5</td>
<td>97.6</td>
<td>96.3</td>
<td>94.6</td>
<td>92.6</td>
</tr>
<tr>
<td>lambda</td>
<td>5.44</td>
<td>4.57</td>
<td>3.91</td>
<td>3.41</td>
<td>3.01</td>
</tr>
<tr>
<td>mp (g/sm²)</td>
<td>6.5</td>
<td>5.25</td>
<td>4.41</td>
<td>3.80</td>
<td>3.34</td>
</tr>
<tr>
<td>m (g/sm²)</td>
<td>523</td>
<td>355</td>
<td>255</td>
<td>192</td>
<td>149</td>
</tr>
<tr>
<td>u (m/s)</td>
<td>85.7</td>
<td>64.8</td>
<td>51.5</td>
<td>42.4</td>
<td>35.6</td>
</tr>
<tr>
<td>n (pcs/m²)</td>
<td>546</td>
<td>546</td>
<td>546</td>
<td>546</td>
<td>546</td>
</tr>
<tr>
<td>Zn (mm)</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Ld (mm)</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>$T_{eq}$ (°C)</td>
<td>527</td>
<td>593</td>
<td>652</td>
<td>705</td>
<td>751</td>
</tr>
<tr>
<td>et (%)</td>
<td>15.4</td>
<td>19.1</td>
<td>22.7</td>
<td>26.3</td>
<td>29.9</td>
</tr>
</tbody>
</table>
7.2.5
Experiences from a laboratory unit and pilot plant

Flakt Ross Inc. laboratory unit was designed and fabricated in Toronto and tested in Toledo in 1982 and 1983. The cast iron cylinder was 1.5 meters in diameter and 4.1 meters in face length. Water was distributed to the cast iron cylinder through a wetted felt. The laboratory tests did not involve paper and were used to determine the transfer to the cast iron dryer and to come up with a design that was compatible with a modern paper machine.

The tested gas fired paper dryer was the type presented in paragraph 5.9.

About 90% of the air is recirculated around the nozzle box system. About 10% of the air is brought in for combustion and the equivalent exhaust mass is exhausted through the ports at the end of the dryer.

The results of the laboratory tests in Toledo are shown in figures 37 and 38. Figure 37 shows the heat transfer coefficient versus the jet velocity for a temperature of 760 °C. Figure 38 shows heat flux generated versus the jet velocity for a temperature of 760 °C.

Fig. 37. Heat transfer coefficient of the gas fired paper dryer as the function of jet velocity.

Fig. 38. Heat flux of the gas fired paper dryer as the function of jet velocity.
The Flakt Ross Inc. type gas fired paper dryer was installed in Flambeau Paper at Park Falls, Wisconsin, USA. The trim was 2.440 m at the reel and 2.500 m on dryer number 16. The moisture in the paper at dryer number was 40%. Diameter of the dryer was 1220 mm. Production was 100 short tons/day fine paper (60–178 g/m²). Maximum speed 340 m/min. The gas heated paper dryer achieved a drying rate of 100 kilograms of H₂O/m²/h with low temperature fabrics.

8 ECONOMICAL ANALYSIS

8.1 General

The electric energy consumption of a big paper machine is approximately 9 MW and the steam consumption approximately 24 MW.

The distribution of energy costs and the water removal of a newsprint paper machine is shown in figure 39 when the price relation of electricity/steam is 1.7.

Fig. 39. Energy costs and water removal of a newsprint paper machine.

A typical Sankey-diagram of a paper mills heat energy consumption is presented in figure 40.
8.2 Possibilities for energy savings

In theory it is needed 1.12 kg steam to evaporate 1 kg of water (2300 kJ/kg). In practise the steam consumption is 1.3–2 kg steam/1 kg of evaporated water.

In a back-pressure power plant only 1/5–part of the energy of the fuel can be transferred to electricity. The steam which is coming out of the turbine is still over atmospheric pressure and it can be used in the processes of a factory. The steam condensates to water in the drying cylinders of a paper machine and the condensed water is pumped back to the power plant. So up to 80 % of the energy content of the fuel can be used as heat or electricity. Losses in the boiler are 10–15 %, some presents in the turbine and the rest in the delivery system (radiation etc.).

The principle of the back-pressure power plant is shown in figure 41.
1. Boiler
2. Turbine
3. Generator
4. Pressure-relief valve
5. Cooling of steam (drying cylinders)
6. Feed-water tank
7. Feed water pump
8. High-pressure preheater
9. Water-treatment plant
10. Condens-treatment plant
11. Auxiliary condenser

Fig. 41. The principle of the back-pressure system./34/

Non-condensibles such as air can build up in the dryer section and cause a loss in heat transfer efficiency. A small amount of steam needs to be bled off the system to prevent any buildup. This number can range up to 465 kJ/kg water evaporated with a poor design./2/

Although a good dryer drainage system will never vent steam to maintain differential pressure in the dryers, there are many machines where venting to a condenser or atmosphere is a normal part of operation. This is extremely bad practise. Venting amounting to as much as 1160 kJ/kg of water evaporated is possible./2/

The direct fired system of Flakt Ross Inc. is between 75% and 80% efficient in the transfer of energy to the water or paper. If the exhaust gases are used in the pocket ventilation system of the paper machine, the efficiency rises to approximately 95%./32/
The possible energy savings with direct fired heating system are estimated in table 7.

Table 7. Possible energy savings with the direct fired heating system. Drying energy demand 7 GJ/t, board production 200,000 t/a, energy price 50 FIM/MWh.

<table>
<thead>
<tr>
<th>The amount of drying energy produced with the direct fired system (%)</th>
<th>Energy needed for the direct fired system, efficiency 95 % (MWh/a)</th>
<th>Energy needed for the steam system, efficiency 80 % (MWh/a)</th>
<th>Total energy demand (MWh/a)</th>
<th>Total energy costs (milj.FIM/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>486111</td>
<td>486111</td>
<td>24.3</td>
</tr>
<tr>
<td>10</td>
<td>40936</td>
<td>437500</td>
<td>478436</td>
<td>23.9</td>
</tr>
<tr>
<td>20</td>
<td>81871</td>
<td>388889</td>
<td>470760</td>
<td>23.5</td>
</tr>
<tr>
<td>30</td>
<td>122807</td>
<td>340278</td>
<td>463085</td>
<td>23.2</td>
</tr>
<tr>
<td>40</td>
<td>163743</td>
<td>291667</td>
<td>455410</td>
<td>22.8</td>
</tr>
<tr>
<td>50</td>
<td>204678</td>
<td>243056</td>
<td>447734</td>
<td>22.4</td>
</tr>
<tr>
<td>60</td>
<td>245614</td>
<td>194445</td>
<td>440059</td>
<td>22.0</td>
</tr>
<tr>
<td>70</td>
<td>286550</td>
<td>145833</td>
<td>432383</td>
<td>21.6</td>
</tr>
<tr>
<td>80</td>
<td>327485</td>
<td>97222</td>
<td>424707</td>
<td>21.2</td>
</tr>
<tr>
<td>90</td>
<td>368421</td>
<td>48611</td>
<td>417032</td>
<td>20.9</td>
</tr>
<tr>
<td>100</td>
<td>409357</td>
<td>-</td>
<td>409357</td>
<td>20.5</td>
</tr>
</tbody>
</table>
8.3
Other possibilities for savings

Table 8 shows Flakt Ross Inc.'s estimation of the total costs of installing ten steam dryers or two gas heated paper dryers. Cost comparison is based on an assumption that 5 steam-heated paper dryers can be replaced with one gas heated paper dryer.

Table 8. Cost comparison: gas heated paper dryer/steam heated paper dryer./15/

<table>
<thead>
<tr>
<th></th>
<th>STEAM DRYERS</th>
<th>GAS DRYERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production increase, %</td>
<td>20 %</td>
<td>20 %</td>
</tr>
<tr>
<td>Number of dryers</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Approx. capital cost for installation, FIM</td>
<td>6.000.000</td>
<td>12.000.000</td>
</tr>
<tr>
<td>Machine changes, FIM</td>
<td>14.000.000</td>
<td>0</td>
</tr>
<tr>
<td>Machine downtime, days</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Lost production, FIM</td>
<td>10.000.000</td>
<td>2.680.000</td>
</tr>
<tr>
<td>TOTAL COMPARATIVE COST, FIM</td>
<td>30.000.000</td>
<td>14.680.000</td>
</tr>
</tbody>
</table>

In figure 42 it is shown the space savings with the application shown in paragraph 5.6 (direct fired system based on radiation). Technical parameters:

- paper weight 60 g/m²
- machine width 2.350 m
- production 2540 kg/h
- production speed 300 m/min
- steam heated version: 28 drying cylinders, d = 1500 mm
- gas heated version: 15 drying cylinders, d = 2000 mm
Fig. 42. Space savings with the direct fired system/9/. 
MARKET POTENTIAL

Estimated increase of drying cylinders is calculated in table 9. The estimated energy consumption is calculated in table 10. The estimated production capacity increase is based on information from FAO's report /35/.

Table 9. World total paper and paperboard capacity/35/ and estimated amount of cylinders.

<table>
<thead>
<tr>
<th>Region</th>
<th>1990</th>
<th>1995</th>
<th>1995-</th>
<th>Machine</th>
<th>Cylinders</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1990</td>
<td>1995</td>
<td>1995-</td>
<td>Total</td>
<td>Total</td>
<td>of</td>
</tr>
<tr>
<td></td>
<td>1000 k/</td>
<td>2000 k/</td>
<td>1000 k/</td>
<td>1000 k/</td>
<td>(100,000</td>
<td>cylinders</td>
</tr>
<tr>
<td></td>
<td>1000 k/</td>
<td></td>
<td></td>
<td></td>
<td>turbines)</td>
<td>per year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern America</td>
<td>95289</td>
<td>104879</td>
<td>9990</td>
<td>391800</td>
<td>1049</td>
<td>26220</td>
</tr>
<tr>
<td>Japan</td>
<td>36778</td>
<td>37706</td>
<td>6978</td>
<td>1395600</td>
<td>377</td>
<td>9427</td>
</tr>
<tr>
<td>Western Europe</td>
<td>69079</td>
<td>83278</td>
<td>16199</td>
<td>3239800</td>
<td>853</td>
<td>21320</td>
</tr>
<tr>
<td>Oceania</td>
<td>2058</td>
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<td>32</td>
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<tr>
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<td>167</td>
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<td>39513</td>
<td>7962600</td>
<td>2986</td>
<td>74708</td>
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</table>

Table 10. World total paper and paperboard capacity and estimated energy consumption for paper drying.

<table>
<thead>
<tr>
<th>Region</th>
<th>Capacity</th>
<th>Increase</th>
<th>Energy</th>
<th>Increase</th>
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<tr>
<td></td>
<td>1990</td>
<td>1995</td>
<td>cons. 1995</td>
<td>per year</td>
</tr>
<tr>
<td></td>
<td>1000 k/</td>
<td>1000 k/</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000 k/</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Northern America</td>
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<tr>
<td>World total</td>
<td>260496</td>
<td>298831</td>
<td>39513</td>
<td>7962600</td>
</tr>
</tbody>
</table>

If 10% of the total energy is produced with gas.
CONTINUATION OF THE PROJECT

Next phase (phase 2) of the project should be started immediately after this preliminary study (phase 1).

Phase 2: Setting up a development group

After phase 1 there should be enough data and evidence that paper machine manufacturers can make decision if they want to participate the development project. In phase 2 the market potential of new cylinder heating method is estimated more accurately. Economical benefits and business strategy for natural gas suppliers, paper producers and paper machine manufacturers is analysed. Agreements are made between possible partners which are ready to start a more concrete development project.

Phase 3: Production of a prototype

The actual development work contains the thoroughly made modelling of heat transfer. After calculations preliminary and machine shop drawings and dimensioning of the cylinder and burner section can be made.

Cylinder, burner and another parts are manufactured after machine shop drawings. Assembling work is done and the equipment is tested.

Test runs are analysed and modifications are made.

Phase 4: Pilot plant tests

Productional pilot plant tests can be made after successful prototype tests. A suitable pilot plant factory is searched, plans for real tests are made. Pilot plant equipment is designed and manufactured. Tests are made and analysed.

Phase 5: Marketing and production

Market efforts can be started already during pilot plant test runs. Massproduction can be started after successful pilot plant tests.
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