Energy consumption reduction in tissue drying methodology.

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Abstract: It is well known that drying tissue paper using high temperature and high drying rates is a very inefficient process. In order to reduce the cost of the drying many attempts have been made in the tissue plants to increase the efficiencies in this part of the process.
For this purpose different state of the art methodology for reducing energy costs are analyzed from the author.

In betwwen these methodologies a cogeneration system which feeds the machinery and equipment, is a good tool for reducing energy. A similar system has been supplied by PMT Italia and started up with the aim of reducing thermal costs in a tissue plant. Cogeneration, or 'Combined Heat and Power' (CHP) generation, is the sequential use of the primary energy source to produce two forms of energy at the same time, namely heat and power.
The author analyzes and comments on the results from the recent example based on the experience of the design, installation, start-up and running of a state of the art tissue machine fed with gases coming from a brand new cogeneration plant supplied for this purpose.

Key words: tissue plant, dryness, cogeneration, shoe press, reinforced (or high nip load) Yankee Dryer.

Palavra Chave: Fabrica de Papel Tissue, Secagem, Co-geração, Cilindro Secador "Yankee" reforçado.

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1. INTRODUCTION

At the beginning of 2006 PMT Italia started up jointly with Hayat Group in Izmit Turkey a new plant for the production of high quality bulky tissue to be converted and sold in the large demanding tissue area of the Turkish region.
The project has been developed as a greenfield mill in a 18 months time span jointly between the two companies.
The plant, that is considered one of the most modern in the nation, includes a Crescent Former PMT Italia tissue machine for high-quality tissue paper, four unwind stations, and one PMT Italia winding station for the production of multi-layered types of tissue.
The plant also includes two PMT Italia stock preparation lines with the auxiliary systems necessary for the operation of the machine (steam system, high-performance cogeneration hood, lubrication system, DCS, etc.)

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The main technical parameters are:

- Production at converting : 60.000 tpy AD
- Average daily production: 180 tpd AD
- Max. daily production: 230 tpd AD
- Design speed: 2.200 mpm
- Max. speed: 2.000 mpm
- Average speed: 1.600 mpm
- Range of basis weights at reel: 14-28 g/m²
- The types of paper produced are mainly toilet tissue and kitchen towel.

The unique feature of the Hayat plant is that the design of the machinery has been done in order to optimize the production cycle, the quality of the tissue produced and the energy savings factors.

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2. COGENERATION IN HAYAT TISSUE MILL

Drying tissue paper using high temperature and high drying rates is a very inefficient process. In order to reduce the cost of the drying process many attempts have been done in the tissue plants. For this purpose, as indicated, a cogeneration system has been designed for reducing thermal energy cost in HAYAT Yenikoy Tissue Plant.

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The electrical efficiency in Hayat Yenikoy plant is 33.7 percent and 66.3 percent of energy input is released as residual heat in the waste gases coming from the turbines. These waste gases having a significant temperature (about 500ºC) and ,at high flow rates, can easily be used in a special-design Yankee hood reducing and even eliminating the gas consumption in their air systems depending on the production rates considered. High temperature waste gases are utilized to dry the tissue, then to generate steam and cold water at a constant temperature level. Electrical equipment is needed to distribute the electricity or to produce it in parallel with the utility grid. Hydraulic interconnections are needed to transport cold water or steam wherever it is required.

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The cogeneration system in HAYAT Tissue Plant consists of six basic elements:

- Two 7.5 MW gas turbines, natural gas fired.
- BRUNNSCHWEILER Yankee Hood.
- Two steam boilers.
- Four duct burners (two reserve burners for the hood systems and two reserve burners for the steam boilers, all to be used when the turbines are off).
- Absorption chillers.
- New adapted control system in hood air circuits (for the perfect integration between the operation of the hoods and the turbines).

The gas turbine is designed for continuous operation from idle to full load. The turbines feature the SoLoNO$_x$ system that is a lean premix, low emission combustion system for NO$_x$ control designed to achieve low NO$_x$ and CO.
Selected turbine exhaust mass gas flows and temperatures are suitable for the drying necessities of various tissue grades. Full use of cogeneration gases is desired. Cogeneration gases flow calculated have minimum gas consumption in hood burners. Fans, burners, hood, boilers and chillers are designed according to these new air flows and temperatures.
As a comparison with traditional systems involving a conventional gas-heated hood we can verify the main difference in the operation of a new system.
In fact we can see that the waste energy flows delivered to the atmosphere are reduced with the complete integration of the three processes (Electricity generation, tissue drying and steam generation), which means that the total energetic efficiency of the system is improved. We will quantify this improvement with the actual efficiency parameters normally used in the next chapter (Calculations).

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The main advantages of the system are:

- Better gas energy saving (as no gas is consumed in the hood burners),
- Minimum gas energy loss through chimney because of use of residual thermal energy from cogeneration gases for drying and steam generation.

3. CALCULATIONS

The main features of relevance to the case study under consideration are:

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- Yankee Diameter: 5486 mm
- Yankee Paper Width: 5600 mm
- Yankee Speed: 2000 mpm
- Yankee Production: 7321 kg/h
- Creping Ratio: 16 percent
- Reel Basis Weight: 13 g/m²
- Electrical Energy Production (turbine efficiency): 33.7 percent

There are two gas turbines and each one is producing 7,315 kW @ 15 C° (and 97,000 kg/h of waste gases at 490ºC). In the Turkish energy scenario (as in most countries) the ratio between electricity unit in cost and thermal unit cost is very attractive for optimisation. About 3 kW of electrical energy can be produced using 1 Nm³/h of Natural gas. The rest of the energy will be utilised for the steam generation and chilled water production, apart from the use of the waste gases in the BRUNNSCHWEILER Yankee hoods. Due to the electrical balance of the Hayat Site the generation of electrical energy exceeds the requirements for the HAYAT Tissue plant. For this reason excess electrical energy will be used in a possible other HAYAT plant or can be sold to the grid. Every tissue plant cogeneration system should be designed according to their own necessities.

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In this case waste gases flowing from the turbine exhaust are designed to cover only around 78% of the hood thermal energy requirement at maximum capacity, what this means is that for an average production rate of the machine the gas consumption in the hoods is totally eliminated. The missing 20% thermal energy for the attainment of the maximum production capacity for high grammage tissue (max drying capability) in the machine will be supplied by the standby duct type burner in the hoods circuits. For that case consumed Natural Gas amount is 2300 Nm³/h. @ 15 C° in every gas turbine plus about 210 Nm³/h in every reserve hood burners, always for maximum capacity. See the following graph:

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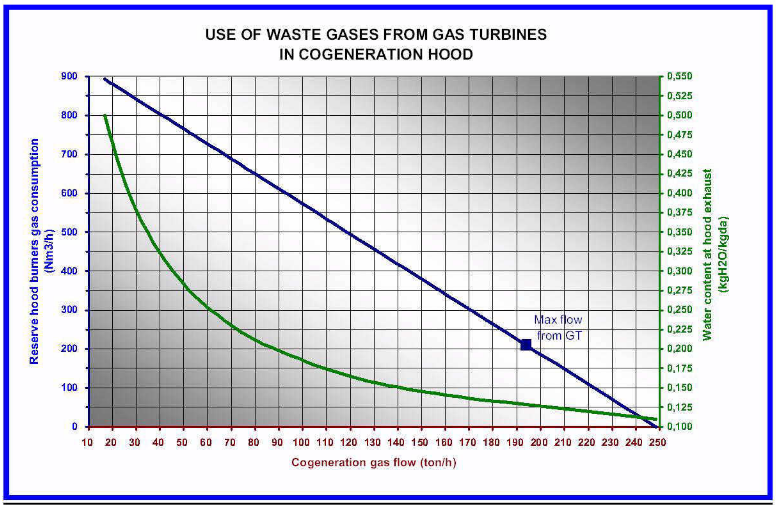

<u>FOR FULL CAPACITY IN TISSUE MACHINE OF 230 TPD</u>**:**

- IN COGENERATION MODE:

Total Natural gas consumed for both electrical and thermal energy production in the tissue plant and other Hayat Plant is 2300 Nm³/h x 2 + 210 Nm³/h = 4810 Nm³/h, at full capacity in the tissue machine (230 tpd).
But on the other hand in this way we are capable to sell an excess of electricity to the net of 3,6 MW

- IN COVENTIONAL MODE:

In the case of the turbines being stopped , the Yankee Hood air circuits will operate as an conventional hood, in typical recirculation mode, with higher moisture content at exhaust, and consequently, reduced flow in exhaust. In this case, the standby burners installed in the exhaust air line will be in operation, in order to produce required amount of steam, but, as the flow given by the Hood air circuits is not enough, an additional external air is needed, to compensate the missing flow in the steam boilers.
In this case the total natural gas consumed is less if compared with the cogeneration mode (959 Nm³/h) but no excess electricity is available to be used in the mill or sold

So the energy cost balance in the two cases (conventional and cogeneration mode) for machine full capacity production is summarized in the hereunder table

FOR MAXIMUM PRODUCTION CAPACITY (230 TPD)

		GOGENERATION HOOD			CONVENTIONAL HOOD		
Production:		Net production at reel =	9,58	ton/h	Net production at reel =	9,58	ton/h
			230,0	ton/day		230,0	ton/day
Energy cost:	Natural gas	unit cost =	0,32	USD/Nm3	unit cost =	0,32	USD/Nm3
		HHV =	10,80	kWh/Nm3	HHV =	10,80	kWh/Nm3
		Gas power cost =	29,63	USD/MWh	Gas power cost =	29,63	USD/MWh
	Electricity	unit cost when buying =	80,00	USD/MWh	unit cost when buying =	80,00	USD/MWh
		unit cost when selling =	90,00	USD/MWh	unit cost when selling =	90,00	USD/MWh
	Steam	unit cost =	32,00	USD/ton	unit cost =	32,00	USD/ton
		Latent heat at 8 bar =	2029,50	kJ/kg steam	Latent heat at 8 bar =	2029,50	kJ/kg steam
		Steam power cost =	56,76	USD/MWh	Steam power cost =	56,76	USD/MWh
Natural gas:	Gas Turbines	mgas =	3772	kg/h			
		gas density =	0,82	kg/Nm3			
		Vgas =	4600	Nm3/h			
		Cost =	1472	USD/h			
	Yankee hoods	mgas =	172	kg/h	mgas =	786	kg/h
		gas density =	0,82	kg/Nm3	gas density =	0,82	kg/Nm3
		Vgas =	210	Nm3/h	Vgas =	959	Nm3/h
		Cost =	67	USD/h	Cost =	307	USD/h
Electricity:	Cost:	Total elect. power consumed at the plant=	11,0	MW	Total elec. power consumed at the plant=	10,0	MW
		unit cost =	0,0	USD/MWh	unit cost =	80,0	USD/MWh
		Cost =	0,0	USD/h	Cost =	800,0	USD/h
	Income:	Total electricity produced at the plant =	14,6	MW			
		Excess of electricity sold to the net =	3,6	MW			
		Income	326,7	USD/h			
Steam:	Cost:	Steam consumption =	9,0	ton/h	Steam consumption =	9,0	ton/h
		unit cost =	0,0	USD/ton	unit cost =	32,0	USD/ton
		Cost =	0	USD/h	Cost =	288	USD/h
		Cost to produce a ton of paper at reel =	126,5	USD/ton	Cost to produce a ton of paper at reel =	145,5	USD/ton

In the table we can see that there is a net reduction in the energy cost consumed to produce a ton of paper on the reel of (145.5 – 126.5) = 19.0 USD/ton of paper on the reel. So a 13% of reduction.

In this table we have not considered the income related to the excess of steam produced for ancillary equipment.

For 8000 h/yr, we would have 19.0 USD/ton x 9.58 ton/h x 8000 h/yr =1,456,160 USD/yr. It should be noted that no consideration of the income related to the excess steam produced for ancillary equipment or chilled water production has been mad.

FOR A REDUCED CAPACITY IN TISSUE MACHINE TO 192 TPD:

If we now repeat the same comparison for a reduced capacity of 192 TPD (and no additional gas consumption required in hood burners) we obtain the data summarized in the following table.

FOR A REDUCED PRODUCTION CAPACITY (192 TPD)

		GOGENERATION HOOD			CONVENTIONAL HOOD		
Production:		Net production at reel =	8,00	ton/h	Net production at reel =	8,00	ton/h
			192,0	ton/day		192,0	ton/day
Energy cost:	Natural gas	unit cost =	0,32	USD/Nm3	unit cost =	0,32	USD/Nm3
		HHV =	10,80	kWh/Nm3	HHV =	10,80	kWh/Nm3
		Gas power cost =	29,63	USD/MWh	Gas power cost =	29,63	USD/MWh
	Electricity	unit cost when buying =	80,00	USD/MWh	unit cost when buying =	80,00	USD/MWh
		unit cost when selling =	90,00	USD/MWh	unit cost when selling =	90,00	USD/MWh
	Steam	unit cost =	32,00	USD/ton	unit cost =	32,00	USD/ton
		Latent heat at 8 bar =	2029,5	kJ/kg steam	Latent heat at 8 bar =	2029,5	kJ/kg steam
		Steam power cost =	56,76	USD/MWh	Steam power cost =	56,76	USD/MWh
Natural gas:	Gas Turbines	mgas =	3772	kg/h			
		gas density =	0,82	kg/Nm3			
		Vgas =	4600	Nm3/h			
		Cost =	1472	USD/h			
	Yankee hoods	mgas =	0	kg/h	mgas =	615	kg/h
		gas density =	0,82	kg/Nm3	gas density =	0,82	kg/Nm3
		Vgas =	0	Nm3/h	Vgas =	750	Nm3/h
		Cost =	0	USD/h	Cost =	240	USD/h
Electricity:	Cost:	Total elect. power consumed at the plant=	11,0	MW	Total elec. power consumed at the plant=	10,0	MW
		unit cost =	0,0	USD/MWh	unit cost =	80,0	USD/MWh
		Cost =	0,0	USD/h	Cost =	800,0	USD/h
	Income:	Total electricity produced at the plant =	14,6	MW			
		Excess of electricity sold to the net =	3,6	MW			
		Income	326,7	USD/h			
Steam:	Cost:	Steam consumption =	9,0	ton/h	Steam consumption =	9,0	ton/h
		unit cost =	0,0	USD/ton	unit cost =	32,0	USD/ton
		Cost =	0	USD/h	Cost =	288	USD/h
		Cost to produce a ton of paper at reel =	143,2	USD/ton	Cost to produce a ton of paper at reel =	166,0	USD/ton

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The reduction in the energy cost consumed to produce one ton of paper on the reel is now (166.0 – 143.2) = 22.8 USD/ton. So a 14% of reduction.
In this table we have not considered the income related to the excess of steam produced for ancillary equipment.

For 8000 h/yr, we would have 22.8 USD/ton x 8.00 ton/h x 8000 h/yr =1,459,200 USD/yr. It should be noted that no consideration of the income related to the excess steam produced for ancillary equipment or chilled water production has been made.

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EFFICIENCY COMPARISON

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A comparison in between the two different drying approaches could be interesting also in terms of efficiency.
Hereunder you find this kind of comparison.

a-Energy efficiency, parameters (CONVENTIONAL HOOD)

$$\eta_{\text{DRYING}} = \frac{M_{\text{evap.hood}} \times h_{fg}}{M_{\text{fuel}} \times LHV} = \frac{7171 \text{ kW}}{10526 \text{ kW}} = \mathbf{68\ \%}$$

b-Energy efficiency, parameters (COGENERATION HOOD)

$$\eta_{\text{DRYING+GENERATIONS+BOILER}} = \frac{M_{\text{evap.hood}} \times h_{fg} + W_{x,net} + M_{\text{steam}} \times h_{fg}}{M_{\text{fuel}} \times LHV} =$$

$$\frac{7150 \text{ kW} + 2\text{x}7315 \text{ kW} + 2\text{x}6800 \text{ kW}}{3650 \text{ kW} + 2\text{x}22110 \text{ kW}} = \mathbf{74\ \%}$$

c-Energy efficiency, parameters (COGENERATION HOOD WITH CHILLERS)

$$\eta_{\text{DRYING+GEN.+BO.+ABS.CHILLER}} = \frac{M_{\text{evap.hood}} \times h_{fg} + W_{x,net} + M_{st.} \times h_{fg} + Q_{abs}}{M_{\text{fuel}} \times LHV} =$$

$$= \frac{7150 \text{ kW} + 2\text{x}7315 \text{ kW} + 2\text{x}6800 \text{ kW} + 1\text{x}4650 \text{ kW}}{3650 \text{ kW} + 2\text{x}22110 \text{ kW}} = \mathbf{83\ \%}$$ when we use only one chiller

$$\eta_{\text{DRYING+GEN.+BO.+ABS.CHILLER}} = \frac{M_{\text{evap.hood}} \times h_{fg} + W_{x,net} + M_{\text{steam.}} \times hfg + Q_{abs}}{M_{\text{fuel}} \times LHV} =$$

$$= \frac{7150 \text{ kW} + 2\text{x}7315 \text{ kW} + 2\text{x}6800 \text{ kW} + 2\text{x}4650 \text{ kW}}{3650 \text{ kW} + 2\text{x}22110 \text{ kW}} = \mathbf{93\ \%}$$ when we use two chillers

Where:

- η = efficiency [%]
- $M_{\text{evap.hood}}$ = hood evaporation [kg/**s**]
- h_{fg}= enthalpy of water evaporation at balance temperature [kJ/kg]
- $W_{x,net}$= net power produced by generator [kW]
- M_{steam}= steam mass created in the boiler house [kg/s]
- Q_{abs}= Equivalent heat to chilled water [kW]

- M_{fuel} = gas quantity to the turbine burners (cogeneration case) or to the hood halves (conventional case) [kg/s]
- LHV= gas low heating value [kJ/kg]

4-COGENERATION FEATURES

Desired operation of the cogeneration system as explained before is based on the simplified control of installations which are listed below:

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- Parallel arrangement to simplify controls and enable easy integration between gas turbines and Yankee hoods.
- Control of available pressure in the turbine exhaust.
- Control of balance in the hoods.
- Control of supply temperature.
- Control of Δp in combustion fans.
- No reason for moisture control in the exhaust from the Yankee hood.
- Bypass arrangement.
- Control of pressure in waste heat boiler.

In the following figure a schematic process diagram is shown.

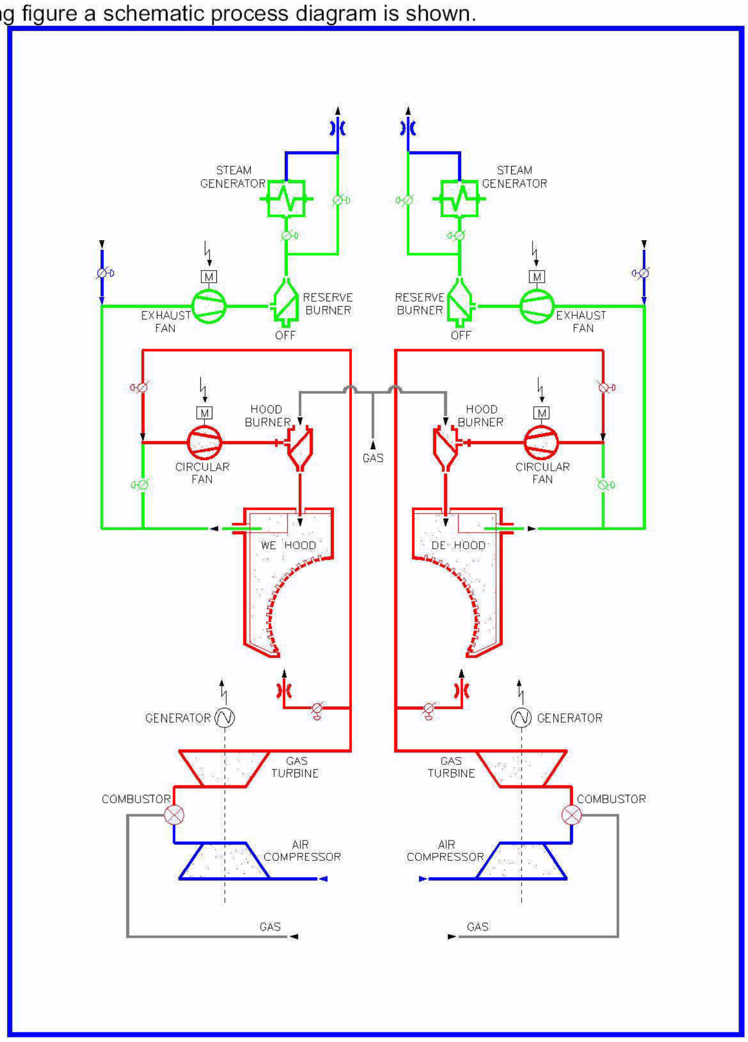

Fig. 1: Integration of gas turbines, Yankee hoods and waste heat boilers for steam generation.

5-SHOE PRESS SYSTEM FEATURES

As already indicated before another implementation on the machine, that might affect the energy consumption reduction, is that the design has been provided in order to be easily retrofitted with shoe press technology.
For this reason the following features have been applied to the press and YD sections:

- The design of the felt run has been carried out with one press solution with the possibility to install the shoe press in a short shut down period;
- The large diameter press has been supplied with no driven configuration. The SPR can be re-used for felt conditioning in the shoe press configuration
- The YD provided by PMT INDUSTRIES LIMITED (PMT Italia's fully owned UK subsidiary) , has been supplied as high load dryer allowing to work up to 170 KN/m nip

The design of this solution allows to have versatility in the requirement for the tissue manufacturer. In fact a shoe press can be used against the Yankee to increase post press dryness by utilising higher line loads than a conventional suction pressure roll (in this way the energy consumption is reduced having higher dryness at the hood inlet) or, by reducing the line load, can reduce the loss in bulk associated with pressing as indicated in Fig.3 .

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In any case with the introduction of the shoe press to tissue machines, the Yankee dryer needs to be able to operate with an external line load of up to 170 kN/m, as opposed to the conventional 90 kN/m. But, there must be no loss in drying capacity as the Yankee may still be used with the conventional 90 kN/m suction presser roll.
This presents some potential problems. High external line loads create high fatigue stresses in the shell; to reduce the stresses to an acceptable level the shell strength has to be increased. However, an increase in shell thickness (the conventional way to increase shell strength) reduces heat transfer (flux) and this results in less drying. It also increases the possibility of shrinkage / porosity reducing the tensile strength and quality of the casting. Both these potential problems have to be addressed.

5.1) Design of high load Yankee Dryers

The heat transfer problem was solved 40 years ago with the development of the ribbed shell. If we compare the heat flux through a plain bore shell vs. a ribbed bore, for the same pressure and line load conditions, the ribbed bore is higher. This can be illustrated by using FEA (Finite Element Analysis) model to show the distribution of heat flow (flux) through a section of a Yankee shell when it is producing tissue.

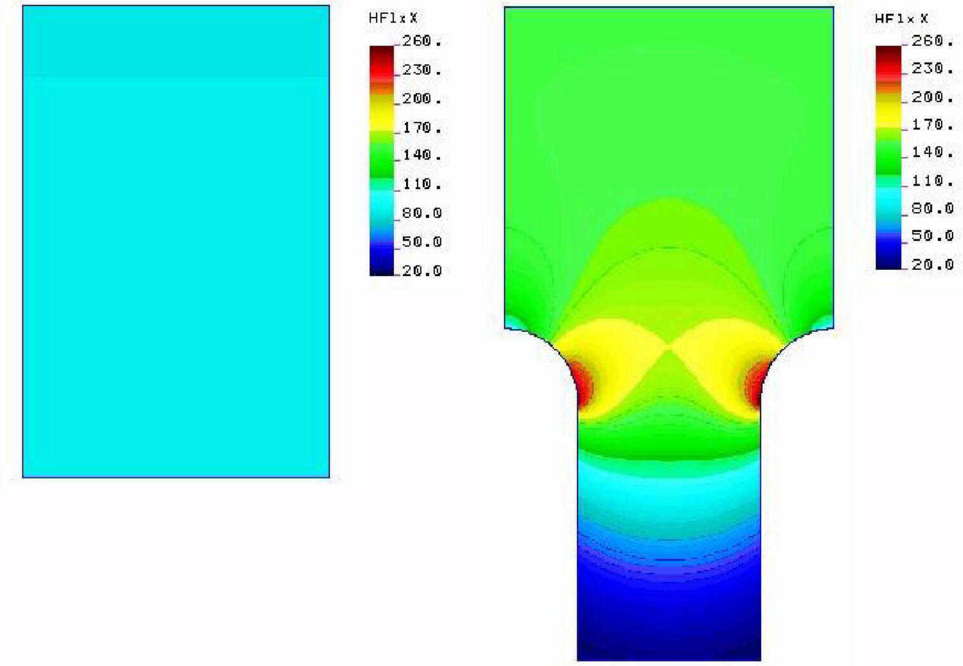


Figure 3: Heat Flow through a Plain Bore & Ribbed Bore Yankee Shell

The model in figure 4 shows a section of a plain bore shell on the left and a ribbed bore on the right. On the inside of the plain bore shell there is a layer of condensate which acts as a barrier to the heat flow thus reducing the overall heat transfer and therefore drying capacity. The ribbed bore only has the insulating condensate layer at the bottom of the grooves with the rest of the rib in direct contact with the steam. The heat flow pattern on the ribbed shell shows that most of the heat transfers from the side of the rib just above the condensate layer, this is because there is no condensate layer to insulate and restrict the heat transfer and there is less iron shell material to pass through than the rest of the rib. On average the rib design has approximately 30 % larger heat transfer than a corresponding plain bore design with turbulator bars and approximately 50 % larger heat transfer than a corresponding plain bore design without turbulator bars.

But, with the increase in line loads, further developments are needed. For a high external line load the shell second moment of area needs to be increased to maintain acceptable shell stress levels. This can be done in two ways, figure 5:

i) by increasing the rib height or

ii) by increasing the root thickness.

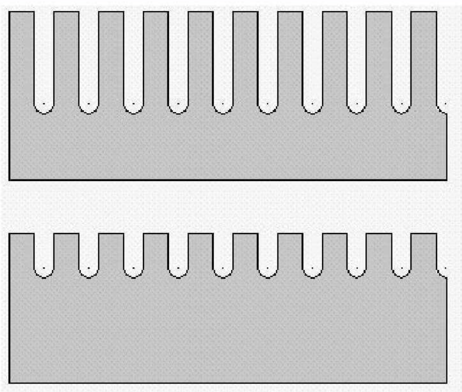


Figure 4: Alternative Design Ribbed Bore Yankee Shells

The increased rib height option has the disadvantages of a greater overall thickness and increased cost of machining; however, it has the advantage of higher heat transfer.

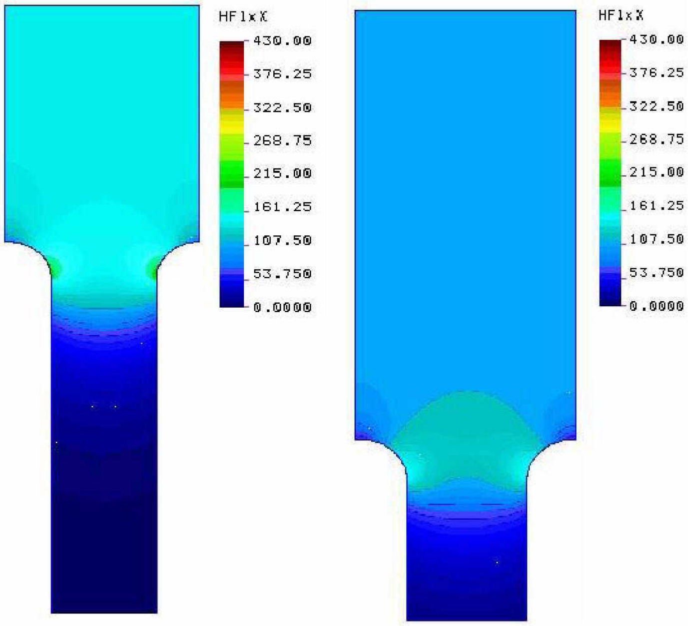


Figure 5: Heat Flow through Alternative Design Ribbed Bore Yankee Shells

The model in figure 6 shows a section of the increased rib option on the left and the increased root option on the right. As shown before most of the heat flows through the rib just above the condensate layer, however, in the case of the deep rib design the heat flow is larger because there is less metal between this area and the outside of the shell. It should be noted that there is little or no heat flow through the top of the deep rib, the additional height of the rib provides strength only (by increasing the second moment of area), it is the reduction of root thickness that increases the heat flow. The similarity of root thickness makes the deep rib design comparable in drying to a conventional low line load Yankee.

5.2) Casting of high load Yankee Dryers

The cast thickness of the shell for high load YD is 50% thicker than a conventional ribbed shell and casting quality must be maintained.
Over the last 50 years the quality of PMT Ind castings has been improved dramatically. Specially developed Class 60 shell material and optimised foundry practice ensure that Yankee dryers have the optimum strength, conductivity, and wear & corrosion resistance characteristics with minimal variation along the length of the shell. As a result of these developments, the Yankee castings have:

- less surface defects
- less through shell leaks
- better radiographs, which along with 100 % shell ultrasonic examination are part of a rigorous Quality control assessment.

Today in addition to the experience and ongoing development PMT Ind now has another sophisticated tool which gives an advantage over the predecessors: the computer. A recent investment in a state of the art casting software package now gives PMT Ind the chance to model a casting without the time and expense of making a casting. This, in conjunction with the acquired experience, has enabled us to predict the quality of a casting before any metal is poured.

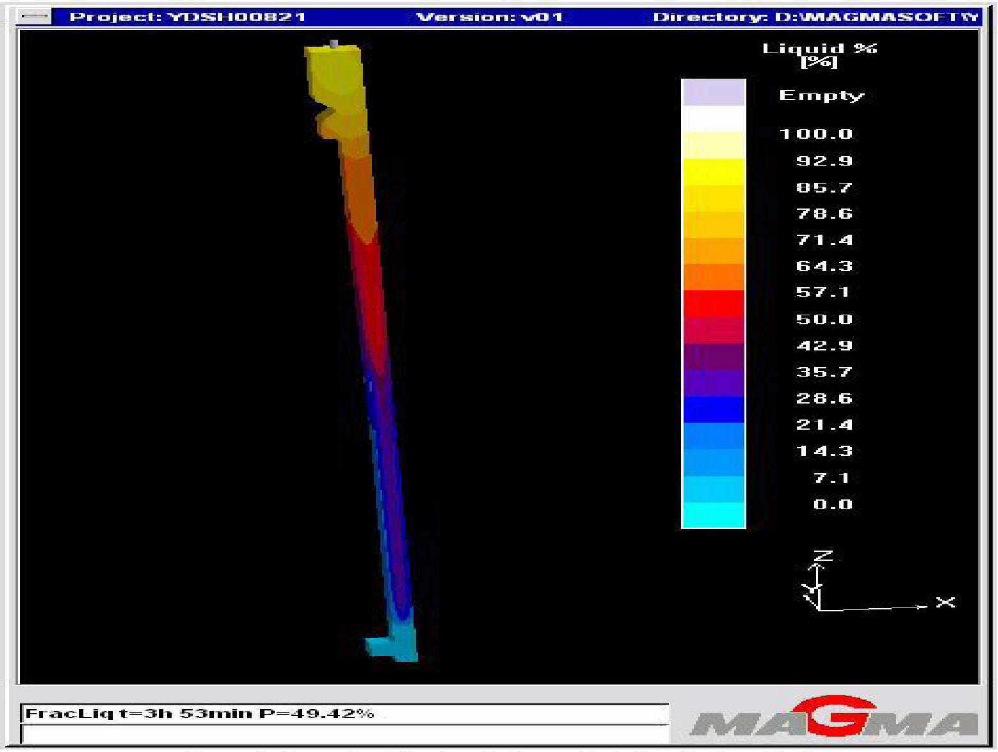


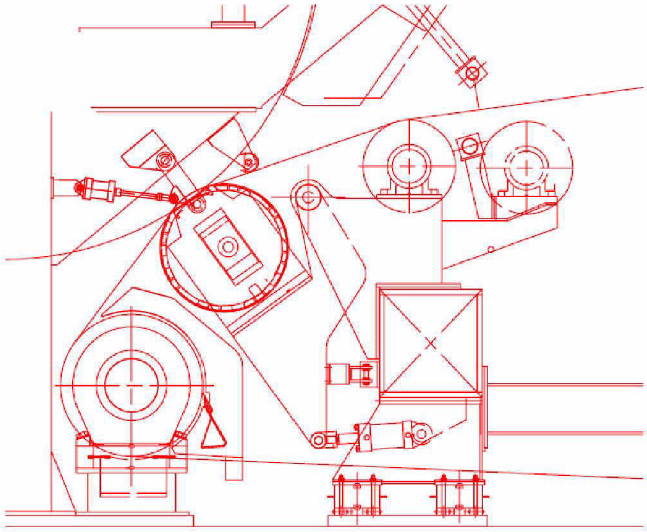
Figure 6: Example of Casting Software Modelling Yankee Shell

The example shows a section of an 18ft Yankee shell where the metal has frozen and where it is still liquid. The Hayat high load YD was the fourth cast in this range of product by PMT Ind. On the 7th November 2003 the first deep rib design Yankee shell was cast 18ft diameter 6.0 m long.

5.3) PMT Italia shoe press design

The PMT shoe presses family varies from standard shoe press size to patented SMARNIP™ solution . All the PMT solutions feature edge relieving system and shoe tilting and can operate in a force line range between 80 KN/m up to 170 KN/m . Shoe length is defined according to the different shoe press adoption.
Shoe presses main features are

- Machine direction elongated nip
- Long nip residence Time
- Possible high Press Impulse
- Control of specific pressure peak intensity
- Gradual specific pressure development in M.D.
- Uniform Cross Machine Nip properties.



Effect of shoe presses on tissue grade could be defined as:

- Higher Bulk at same Dryness
- Or Higher Dryness at same Bulk
- Flexible Nip: no more crown issues: possibility to run any nip
- Better adhesion of sheet on Yankee dryer
- Better moisture profile
- Better creping

The shoe press solution proposed by PMT can be offered in three different ways: for new machines, for easy retrofit in a new machine prepared for (like the case of Hayat) and finally for major tissue machine rebuilds.

6-CONCLUSIONS

The authors have presented with a practical case the innovation that can allow , in a modern tissue plant, to reduce the energy consumptions/ costs.

For the total efficiency point of view cogeneration type drying is clearly the right choice, and it opens a new field in the use of residual energies in the drying processes where very modest attempts in this respect have been carried out in the past. The main innovation of the Hayat project (now, a reality) lies in the fact that no one has ever undertaken an integration at this extent

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Further considerations than could be done, case by case, adopting other different turbines design and features .

Furthermore shoe press technology available among PMT Italia tissue range products combined with reliable high load YD is the right additional tool to implement energy consumption reduction.

Amendments: The author would like to thank you the Hayat Group management and to O. Lopez from Brunnschweiller Spain S.A. , for the contribution to the paper.

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