Verification of Pressure and Temperature of a Modern Precalciner System

Diploma Thesis

Presented by

Erich Schachenhofer

Prepared for

ÖMAG-Montananlagenbau GmbH

Supervisor: Dipl.-Ing. Theodor Mauser

University of Leoben

Department of Metallurgy

Chair of Thermal Processing Technology

Supervisor: Univ.-Prof. Dipl.-Ing. Dr. Harald Raupenstrauch

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AFFIRMATION

I declare in lieu of oath that I did this master´s diploma thesis in hand by myself using only literature cited at the end of this volume.

Erich Schachenhofer

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I dedicate this diploma thesis to my parents, my brother and my sister.

Abstract

Verification of Pressure and Temperature of a Modern Precalciner System

Aim of this diploma thesis was to get more specific and measured data of a modern precalcining system in a Turkish cement plant for further verification of the theoretical calculation. These data were made for an Austrian engineering and project management company, who designed this precalcining system in 2002/2003.

Therefore a measurement assembly was developed to measure pressure and temperature at several positions simultaneously. In addition to the existing measuring points at the preheater tower, new measuring points for hand-held measurement have been installed. The measurements itself were executed with mobile equipment consisting of a control unit, data loggers, thermocouples and differential pressure probes.

The preheater tower is subdivided into measuring sections, the so-called units, according to the cyclone stages, consisting of cyclones, riser ducts and meal pipes. All data of the existing measuring equipment and the additional measuring points were collected and elaborated. Relevant key values like pressure losses as well as temperature of gas and raw materials in cyclones, riser ducts, meal pipes and other components of the precalcining system are stated. Surface temperatures were measured and subsequent calculations of heat losses through surfaces are also headed in this thesis.

Furthermore a heat balance for the preheater tower, including the calciner, was established. Calculations of the heat transfer within cyclones and riser ducts and of the heat content of raw meal in the meal pipes are provided. In the top stage of the preheater tower (twin cyclones of the calciner string) one cyclone unit was analysed in more detail for a heat balance.

Summing up, the recorded data are a basis for improvement and a verification of the company-internal calculation program including the heat calculation and geometrical design.

Kurzfassung

Überprüfung von Druck- und Temperatur eines modernen Vorkalzinierungs-Systems

In dieser Arbeit wurden spezifische Messdaten eines modernen Vorkalzinierungs-Systems in einem türkischen Zementwerk zur Verifizierung der theoretischen Berechnungen einer österreichischen Firma der Montananlagenbauindustrie, welche diesen Wärmetauscherturm im Jahr 2002/2003 entwickelte, erstellt.

Im Zuge dessen wurde ein Messaufbau entwickelt, um Druck und Temperatur an unterschiedlichen Positionen simultan messen zu können. Zu den vorhandenen Messpunkten des Wärmetauscherturms wurden zusätzliche Messstellen vorbereitet und installiert. Für die Messung selbst kam mobiles Equipment unter anderem bestehend aus Control-Unit, Datenloggern, Thermoelementen und Differenzdruck-Messgeräten zum Einsatz.

Der Wärmetauscherturm unterteilt sich in verschiedene Messbereiche, die sich in der Regel aus Zyklonen, Steigrohren und Mehlleitungen zusammensetzen. Alle Messergebnisse der bestehenden und neu errichteten Messstellen wurden gesammelt und schließlich ausgewertet. Relevante Kennziffern wie Druckverluste, Temperaturen bezüglich Gas und Material in Zyklonen, Steigrohren und Mehlleitungen sowie anderen Komponenten des Vorkalzinierungs-Systems sind ebenso dokumentiert. Messungen der Oberflächentemperaturen und daraus folgende Berechnungen zum Wärmeverlust zeigen Möglichkeiten für weitere technische Verbesserungen auf.

Des Weiteren wurde eine Wärmebilanz für den Wärmetauscherturm einschließlich Vorkalzinierung erstellt. Berechnungen zur Wärmeübertragung in Zyklonen und Steigrohren, als auch zum Wärmeinhalt des Rohmehls in den Rohmehlleitungen sind zusätzlich angeführt. Im obersten Bereich des Wärmetauscherturms (Doppelzyklon des Kalzinatorstrangs) wurde unter Einbeziehung der Messergebnisse eine Wärmeberechnung durchgeführt.

Zusammenfassend ist zu sagen, dass die aufgezeichneten und ermittelten Daten eine Grundlage bieten, um Verbesserungen im Hinblick auf firmeninterne Berechnungs- und Simulationssoftware, Wärmeberechnungen und das geometrisches Design zu erzielen.

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1 Introduction

ÖMAG-Montananlagenbau GmbH is an engineering and project management company. It is acting mainly in the field of engineering and construction of new cement plants and modernisation of existing plants.

ÖMAG-Montananlagenbau GmbH developed precalcining systems for the cement industry. The technical procedure of the system includes the burning of powdery raw materials with low energy consumption and low NO_x-emissions.

These precalcining systems are a cross flow system, ÖMAG 1® (Figure 2) and a parallel flow system ÖMAG 2 ®. (Figure 3)

1.1 Conceptual Formulation

The precalcining system named above is part of a cement plant in Turkey. It is installed in kiln line III at cement plant of NUH CIMENTO SANAYAI A.S. company in Hereke, a small town near Istanbul, and has a production capacity of 6500 tonnes clinker per day. (Figure 1)

This reference plant was designed by and constructed under supervision of ÖMAG-Montananlagenbau GmbH. It is object of the investigations with respect to measurement of pressure and temperature in running business of the precalcining system.

The design of the preheater tower is innovative and based on new technology and design. Numerous scientific experiences and detailed technical data of operating plants with the improved technical installation as well as more exact and detailed information about pressure and temperature ratios should lead to better engineering in future.

1.2 Objective Target

A special measurement method should be developed for the precalcining system to get additional data for further verification of the theoretical company-internal calculation. Target is to establish an assembly of simultaneous measurement at the preheater tower to get data about the pressure losses of cyclones, riser ducts and other components of the system as well as temperature ratios of gas and materials of the different cyclone stages.

After creating a measuring concept, measuring points should be defined, adjusted measuring equipment be composed and acquainted accordingly.

In field tests all data should measured, collected and elaborated. Conclusions about the measuring method and its effectiveness should be drawn from the results of the measurements. The data are to be to be prepared for further optimisation of the preheater system engineering.

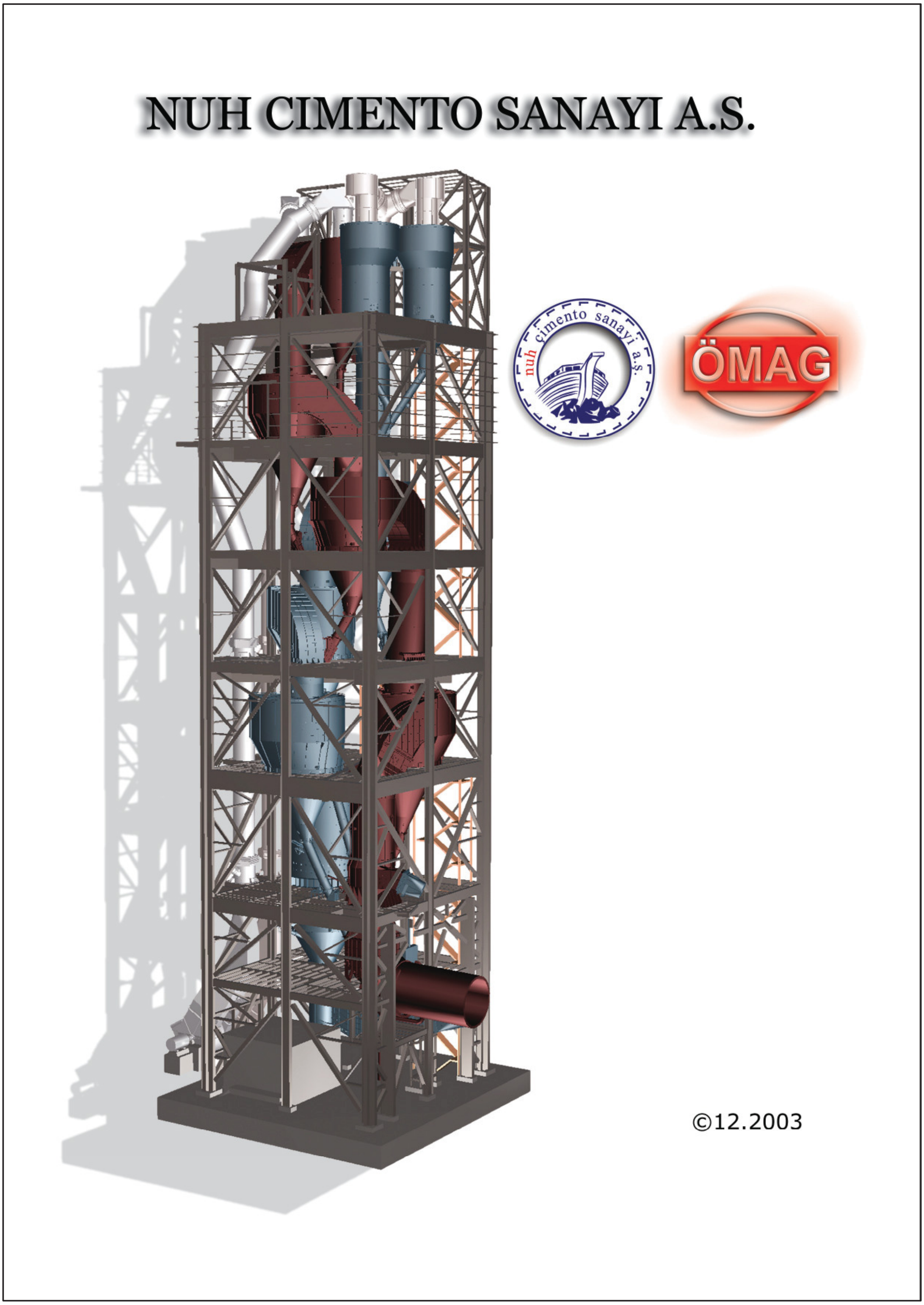


Figure 1: Nuh Cimento Sanayi A.S. – Preheater designed by ÖMAG-Montananlagenbau GmbH

2 Basics

2.1 Preheating and Precalcining – Theoretical View

Preheating of raw material is a decisive development in the heat economy of cement production. The process takes place in a preheater tower which consists of gas ducts, cyclones, mealpipes, and calciner(s).

The two main tasks of the preheater tower are drying and preheating the raw material and precalcining of limestone. Such systems are lowering the energy consumption and are able to achieve with exhaust gas temperature of about 280℃ or even lower [17].

If considered as a whole, the cyclone suspension preheater operates in gradual counter-current wise mode. The raw material flow is in the opposite direction to the gas flow which is coming from the kiln.

The heat transfer takes effect in the individual gas ducts and cyclones of the suspension preheater whereas approximately 80 % of the heat transfer occurs in the gas ducts and only 20 % of the total heat transfer is carried out in the cyclones.

A cyclone is a conical vessel and the key component of the suspension preheater. The dust-bearing gas-stream passes tangentially into the cyclone. This produces a vortex, the gas then leaves the cyclone upwards through the so called dip pipe or immersion tube. The solids in the gas stream are thrown to the outside by centrifugal action and leave through the lower conical part of the cyclone, the so called apex. Most commonly encountered suspension preheaters have four cyclone stages, but up to 6 stages have been built. In a simple 4 stage preheater, the hot material that leaves the base of the preheater string into the kiln is up to 40 % calcined, so the kiln has less subsequent processing to do, and can therefore achieve higher specific output compared to dry kilns of same length and diameter [13].

A suspension preheater combined with a calciner enables higher calcination grades up to 95 %. Due to low heat transfer efficiency of the kiln, the output of a preheater system can be increased for a given kiln size by burning the raw mix outside the kiln. Therefore part of the fuel necessary is injected into a specially combustion chamber at the base of the preheater, called the calciner [13].

Main process of the calciner is to decarbonise limestone. The chemical reaction is $CaCO_3 \Leftrightarrow CaO + CO_2$ (g). The equilibrium of calcium carbonate between calcium oxide and carbon dioxide exists at any temperature but is dependent on partial pressure of both. Economically useful rate of decarbonisation is achieved at total atmospheric pressure of 101 kPa and 898 ℃ and should not be below 800 ℃ [15][17].

In general there are two ways of precalcining: air through and air separate precalciners. If the combustion air for both the kiln fuel and the calciner fuel all passes through the kiln it is about an air through precalciner. This kind of precalciner can burn up to 30 % of its fuel in the calciner. If more fuel is injected in the calciner, the extra amount of air drawn through the kiln would cool the kiln flame excessively [13][16].

Better development is the air separate precalciner, in which the hot combustion air for the calciner arrives in a separate tertiary air duct directly from the clinker cooler, bypassing the kiln. Typically 60 to 75 % of the complete fuel used is burned in the precalciner. In these systems, the feed entering the rotary kiln has a calcination degree between 95 and 99 %. The kiln only has to raise the feed to the sintering temperature. In theory the maximum efficiency would be achieved if all the fuel were burned in the preheater, but the sintering operation involves partial melting and nodulization to make clinker, and the rolling action of the rotary kiln remains the most efficient way of homogenisation and clinkering the material [13].

Large modern preheating and precalcining systems typically have two parallel strings of 4 or 5 cyclone stages. The ÖMAG 1® System uses also 2 strings, one attached to the kiln, the so called kiln string, and the other attached to the calciner, the so called calciner string, which is connected with the cooler through the tertiary duct [13].

Low energy consumption, higher capacities, controlling NOx-formation and high calcination grades sum up the advantages of these systems and are preferred for installations in industry [16].

2.2 Experience and Outlook on Development of Precalciner Plants

Nowadays new rotary kiln systems are usually being constructed with the latest precalciner technology. A lot of investigations on rotary kiln systems with precalciner technology are fitted with tertiary air ducts [20].

As the guaranteed performance of the kiln systems has been reached for the most part, the focus today is predominantly on the reduction of emissions, lowering energy consumption and securing the plant availability [20].

Conventional rotary kiln systems are usually operated with only one primary firing unit. The fuel proportion, which is fed to the calciner in these precalciner systems, varies between 50 and 65 % of the entire firing heat capacity. This way, the kiln meal can already be calcinated to a high degree before entering the kiln. As a result, the kiln can be built smaller and be operated with increased specific performance. Other advantages of precalciner are the possibilities of NOx reduction by using a staged combustion and a more flexible use of secondary fuel with different calorific values [20].

Alongside topics such as refractory wear, energy consumption and emissions situation, more experience for utilising secondary fuel is desirable. For the plant operator, the main focus is usually related to questions concerning fuel characteristics, fuel preparation and the effects on emissions, the material cycles and influences to the plant operation conditions [20].

Many different secondary fuels can be used in precalciner plants. Among these are reprocessed manufacturing and industrial residues, paper and plastics and also rubber scraps, wood and used tires. Depending on the process, especially fuel with a low calorific value can be used in the calciner. The calorific values, depending on ash and moisture content, are between 10000 and 30000 kJ/kg. Investigations, on substituting the firing heat capacity for the calciner with usual secondary fuels, have not shown any negative effects on the emission situation of the kiln system [20].

Through the correct use of specific secondary fuels even a NO_x reduction can be achieved, if the secondary fuels are of high reactivity and have a high volatile content [20].

Secondary fuels may have higher chlorine contents in comparison to standard fuel. This can lead to an increase in chloride input into the kiln system. To limit/reduce the chlorine cycle and the result of stronger tendency for coating as well as higher chlorine content of the produced clinker itself, bypass systems are installed. Investigations have demonstrated, that the gas bypass in plants with precalciner technology can be operated more effectively than in conventional plants. The material cycles in kiln plants can be influenced by the fuels used in the calciners because of their different physical properties, such as, e.g., grain size. Finely prepared fuel is swept along with the gas flow and will burn in the calciner. Coarser fuel can fall into the kiln inlet and be transported into the kiln along with the meal. There, it will burn and can lead to an increased local temperature, which will result in increased sulphur cycles and coating tendencies. An increased coating formation in the kiln path can lead to the shift of air conditions in the plant. Less air passes through the kiln and more air passes through the tertiary air ducts. As operation experience at different precalciner plants has demonstrated, a targeted regulation of the tertiary air volume flow can present an effective countermeasure [20].

For regulating tertiary air quantities flaps or sliders have been installed in the tertiary air ducts of the precalciner kilns. These regulating organs frequently only have a very short service life, due to the high temperatures and dust contents. In many precalciner plants it has therefore not yet been possible to regulate the air condition to the desired extent. New materials for regulation instruments could improve these troubles [20].

Generally one of the most important aims and developments will be reducing the amount of fossil fuels and replacing them to a higher grate with secondary fuels. Therefore development will concentrate on optimisation of regulating instruments to reach optimal combustion with low emissions and low specific energy consumption.

2.3 Precalcining System by ÖMAG-Montananlagenbau GmbH

2.3.1 General Notes

Conceived in general terms ÖMAG´s precalcining systems are designed for very low heat consumption and for very low NO_x emissions. A five-stage-type can easily reach heat consumption below 700 kcal/kg clinker, and the optimum heat utilisation generates exhaust gas temperatures lower than 280 °C. The system allows for applying low grade fuels to the calciner. Costs for electric power consumption can be kept down due to low pressure losses of the whole system [7].

2.3.2 Description of ÖMAG´s Precalcining Systems

The precalcining system ÖMAG 1®, cross flow system, is in principle described as follow: Burning powdery raw material in a plant with a parallel working, multistage cyclone preheater with a kiln and a calciner string, a kiln (K) and a cooler (C) wherefrom one part of the gas flow - also referred to as secondary air - streams through the kiln (K) and kiln string whereas the other part of the gas - referred to as tertiary air - is feed to the calciner (Ca1) of the calciner string and flows through the calciner string. The raw material will be preheated in counter current flow to the gas flow in stages, then precalcined and finally sintered [18].

Further the gas flow which is led through the kiln (K) to the calciner (Ca2) of the kiln string. This calciner is fed with fuel in the lower area and above with a further gas flow which comes from the kiln head, too. The other calciner (Ca1) is filled with the complete material and has two burner stages upside the entry of tertiary air gas flow [18].

The powdery raw material gets involved in the system by entering the riser ducts at the meal inlet points (Ic and Ik). See Figure 2 [18].

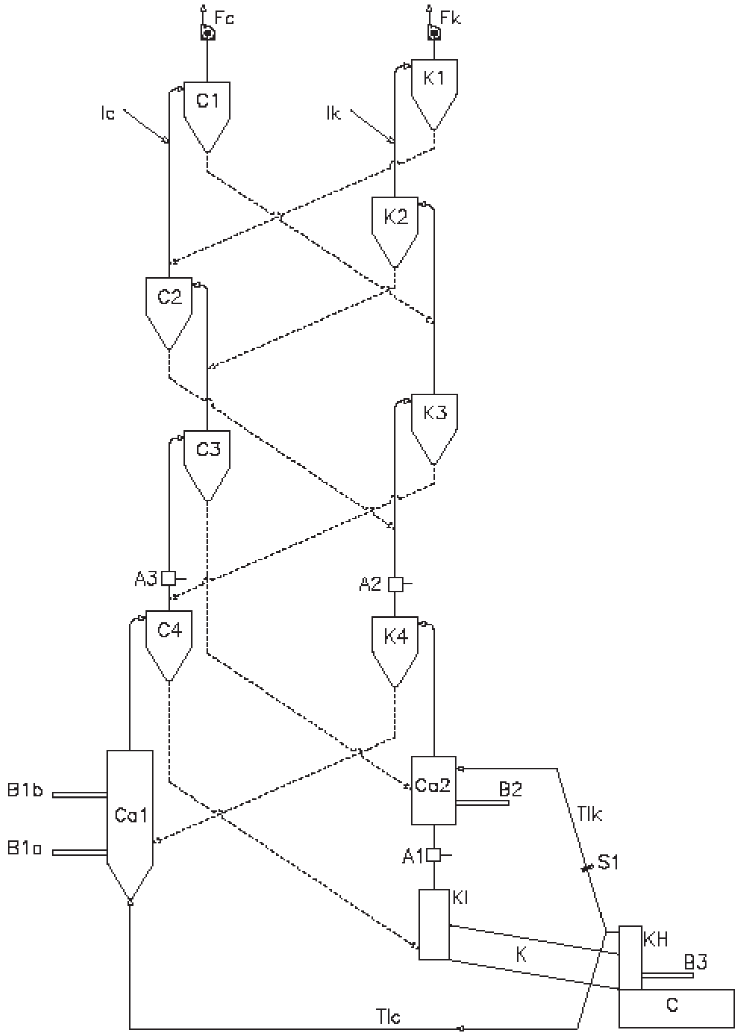
The main aim of this patent is the reduction of NO_x that is a result of the combustion in the kiln (K). Fuel is inserted in the lower part of the calciner (Ca2) of the kiln string so that a zone with reducing atmosphere is given. Most of the No_x resulted by the combustion in the kiln (K) now will be reduced, and preheated air from the tertiary air duct will complete the burning of unburned fuel [18].

The powdery raw material is nearly precalcined in the calciner (Ca2) of the kiln string, then completely calcined in the calciner (Ca1) of the calciner string. Afterwards the material will be separated from the gas in the last cyclone C4 and fed to the kiln [18].

The regulation of combustion air supply is controlled by ID Fans (Fc and Fk) and depends to the kiln head pressure mainly [18].

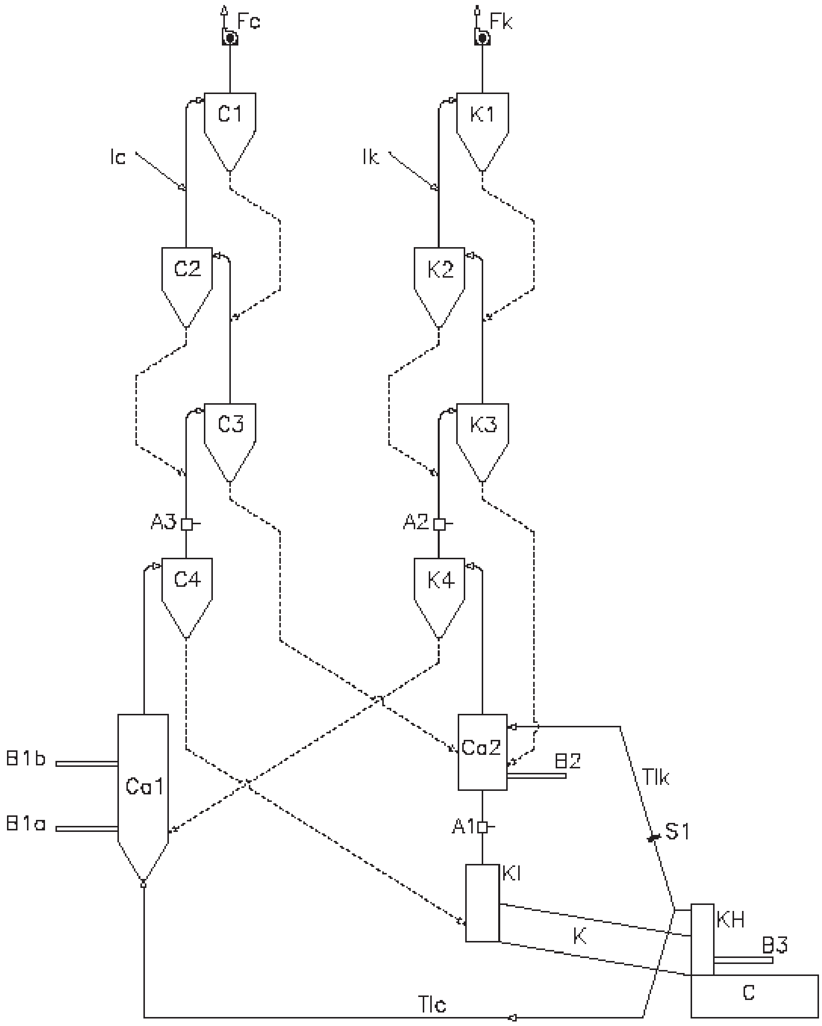
The distribution of fuel feeding reads as follows: 2/6 for the main burner (B3) of the kiln (K), 1/6 for the calciner burner (B2) of the calciner (Ca2) of the kiln string, 2/6 for the calciner burner (B1a) of the calciner (Ca1) in the lower stage, 1/6 for the calciner burner (B1b) of the calciner (Ca1) in the upper stage [18].

This technology can be constructed either as cross flow (Figure 2) or as parallel flow system. (Figure 3)



Fc, Fk…Fan of Calciner/Kiln String
C1-4, K1-4…Cyclones of Calciner/Kiln String
Ic, Ik…Raw Meal Inlet of Calciner/Kiln String
Ca1, Ca2…Calciner
B1a, B1b, B2…Calciner Burner
B3…Main Burner
KI…Kiln Inlet Chamber
K…Kiln
KH…Kiln Head
C…Clinker Cooler
A1, A2, A3…Analysers for Process Gases
S1…Control Flap
Tlc, Tlk…Tertiary Air Duct
Index c…Calciner String
Index k…Kiln String

Figure 2: Precalcining System, ÖMAG 1®, cross flow [19]



Fc, Fk…Fan of Calciner/Kiln String
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S1…Control Flap
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Index c…Calciner String
Index k…Kiln String

Figure 3: Precalcining System, ÖMAG 2®, parallel flow [19]

3 Theory of Measurement

3.1 Temperature Measurement with Thermocouples

In electronics, thermocouples are a widely used type of temperature sensor with a very wide range of temperature (1 K until 3000 K). They can also be used as mean to convert thermal potential difference into electric potential difference. Their advantage is the simplicity of the design and production. They are cheap, interchangeable, and have standard connectors. Fine thermocouples with short reaction times are available for industry as well as robust ones for higher temperatures (> 1500 °C). The main limitation is accuracy; system errors of less than 1 °C can be difficult to achieve [2].

3.1.1 The Principle of Operation

Thermocouples provide a consistent and reasonably accurate way to measure temperature. They utilize the Seebeck effect, whereby two junctions between dissimilar conductors produce a voltage proportional to the temperature difference between them. Due to the effect of thermovoltage, which occurs on the basis of the temperature gradient, a thermocurrent will flow. For good accuracy it is very important that the thermocouple is very homogeneous; at production a special heat treatment near or higher than the range of application of temperature is necessary. A measuring fault from 0,1 K to 0,3 K is achievable whereas the effect of ageing process throughout the usage can lead to deterioration of thermoelectrical homogeneity and consequently of a range of accuracy from 1 K to 100 K [1][2].

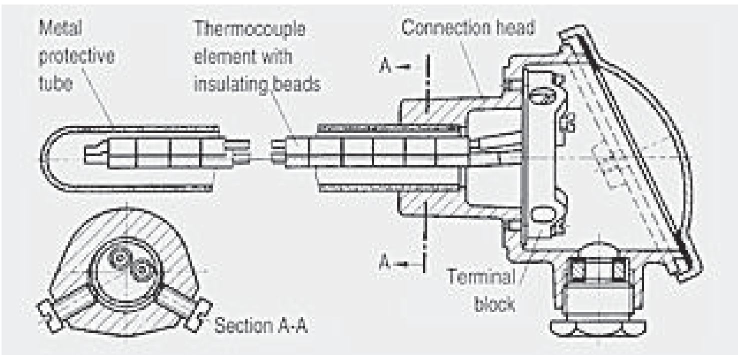

Figure 4: Straight thermocouple with base-metal element Ni Cr/Ni with metal protective tube [10]

It is important to note that thermocouples measure the temperature difference between two points, not absolute temperature [2].

To manufacture a thermocouple two thermoelectric effective homogeneous conductors (thermocouple) are connected electrically at the central ending (measuring point). The other endings (compensating conjunction points) are added with copper cables which are fixed at a voltmeter. The measuring point is exposed to the temperature which will be measured, the compensating conjunction points will be kept on a constant acquainted temperature. The measured thermo voltage corresponds to the temperature difference between measuring point and conjunction points whereas its dimension depends on the combination of materials of the thermocouple (thermoelectric sensitivity) [1][2].

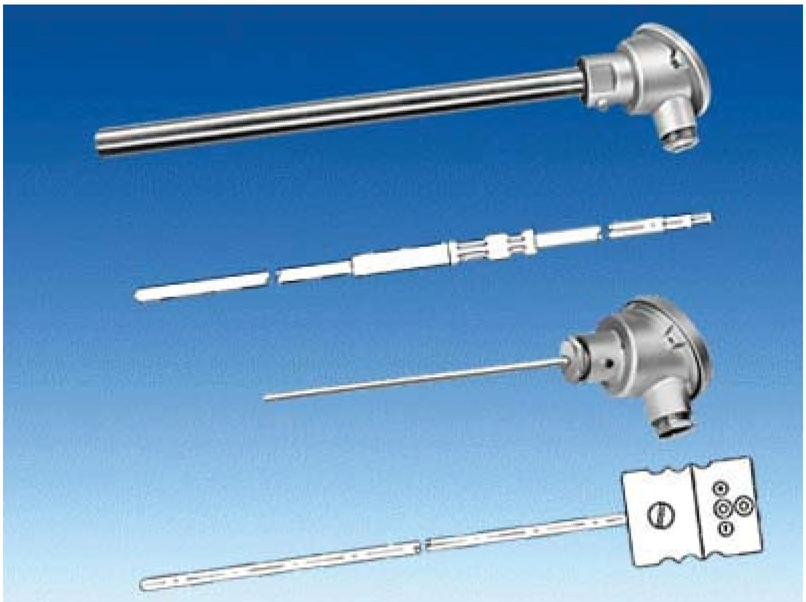

Figure 5: Straight thermocouples [11]

The thermo wires have to be electrically isolated to protect of mutual contact. The working temperature of the thermocouple is limited to the insulating material. For higher temperatures protection tubes made of fused silica (till 1000 °C) or ceramics (till 2000 °C) are necessary [2]. Examples see Figure 4 and Figure 5.

Generally, there are two junctions: the cold junction and the hot junction. Having available a known temperature cold junction, while useful for laboratory calibrations, is simply not convenient for most directly connected indicating and control instruments. They incorporate into their circuits an artificial cold junction using some other thermally sensitive device (such as a thermister or diode) to measure the temperature of the input connections at the instrument, with special care being taken to minimize any temperature gradient between terminals. Hence, the voltage from a known cold junction can be simulated, and the appropriate correction applied. This is known as cold junction compensation [2].

Usually the thermocouple is attached to the indicating device by a special wire known as the compensating or extension cable. The terms are specific. Extension cable uses wires of nominally the same conductors as used at the thermocouple itself. These cables are less costly than thermocouple wire, although not cheap, and are usually produced in a convenient form for carrying over long distances - typically as flexible insulated wiring or multicore cables. They are usually specified for accuracy over a more restricted temperature range than the thermocouple wires. They are recommended for best accuracy [2].

Compensating cables on the other hand, are less precise, but cheaper. They use quite different, relatively low cost alloy conductor materials whose net thermoelectric coefficients are similar to those of the thermocouple in question (over a limited range of temperatures), but which do not match them quite as faithfully as extension cables. The combination develops similar outputs to those of the themocouple, but the operating temperature range of the compensating cable is restricted to keep the mis-match errors acceptably small [2].

The extension cable or compensating cable must be selected to match the thermocouple. It generates a voltage proportional to the difference between the hot junction and cold junction, and is connected in the correct polarity so that the additional voltage is added to the thermocouple voltage, compensating for the temperature difference between the hot and cold junctions [2].

3.1.2 Different Types

A variety of thermocouples are available, suitable for different measuring applications (industrial, scientific, food temperature, medical research, etc.) [2].

The standard for thermocouples is defined in the international norm IEC 584-Part 1, as well as in DIN IEC 584-Part 1 and DIN EN 60584, Part 1. The International Electrotechnical Commission is the international standards and conformity assessment body for all fields of electro technology [1].

For their application the Seebeck-coefficient is of particular importance, characterised by µV/℃. The higher the Seebeck-coefficient, the better is the sensitivity for temperature changes.

3.1.2.1 Type K (Chromel (Ni-Cr alloy) / Alumel (Ni-Al alloy))

DIN IEC 584-Part 1 temperature range: from -270 ℃ to 1372 ℃ [1].

The "general purpose" thermocouple. It is low cost and, owing to its popularity, it is available in a wide variety of probes. They are available in the –200 ℃ to +1200 ℃ range. Sensitivity is approximately 41 µV/℃ [2].

3.1.2.2 Type E (Chromel / Constantan (Cu-Ni alloy))

DIN IEC 584-Part 1 temperature range: from -270 ℃ to 1000 ℃ [1].

Type E has a high output (68 µV/℃) which makes it well suited to low temperature (cryogenic) use. Another property is that it is non-magnetic [2].

3.1.2.3 Type J (Iron / Constantan)

DIN IEC 584-Part 1 temperature range: from -210 °C to 1200 °C [1].

Limited range (–40 to +750 °C) makes type J less popular than type K. The main application is with old equipment that cannot accept modern thermocouples. J types cannot be used above 760 °C as an abrupt magnetic transformation causes permanent decalibration. Type J's have a sensitivity of ~52 µV/°C [2].

3.1.2.4 Type N (Nicrosil (Ni-Cr-Si alloy) / Nisil (Ni-Si alloy))

DIN IEC 584-Part 1 temperature range: from -270 °C to 1300 °C [1].

High stability and resistance to high temperature oxidation makes type N suitable for high temperature measurements without the cost of platinum (B, R, S) types. They can withstand temperatures above 1200 °C. Sensitivity is about 39 µV/°C at 900°C, slightly lower than a Type K. Designed to be an improved type K, it is becoming more popular [2].

Thermocouple types B, R, and S are all noble metal thermocouples and exhibit similar characteristics. They are the most stable of all thermocouples, but due to their low sensitivity at low temperatures (approximately 10 µV/°C) they are usually only used for high temperature measurement (>300 °C) [2][1].

3.1.2.5 Type B (Platinum-Rhodium/Pt-Rh)

DIN IEC 584-Part 1 temperature range: from 0 °C to 1820 °C [1].

Suited for high temperature measurements up to 1800 °C. Long lasting measurements (> 100 h) are possible up to 1700 °C. The Seebeck-coefficient decreases constantly below a temperature of 1600 °C. The thermo voltage changes its algebraic sign between 0 °C and 42 °C. This makes them useless below 50 °C [2][3].

3.1.2.6 Type R (Platinum /Platinum with 7% Rhodium)

DIN IEC 584-Part 1 temperature range: from -50 °C to 1768 °C [1].

Suited for high temperature measurements up to 1600 °C, for permanent use up to 1300 °C. The Seebeck-coefficient is about 12 % higher than the coefficient of type S [3]. The thermocouple is susceptible to impurities of foreign materials caused by diffusion. Low sensitivity (10 µV/°C) and high cost makes them unsuitable for general purpose use [2].

3.1.2.7 Type S (Platinum /Platinum with 10% Rhodium)

DIN IEC 584-Part 1 temperature range: from -50 °C to 1768 °C [1].

Suited for high temperature measurements up to 1600 °C. Low sensitivity (10 µV/°C) and high cost makes them unsuitable for general purpose use as well. Due to its high stability type S is used as the standard of calibration for the melting point of gold (1064.43 °C) [2].

3.1.2.8 Type T (Copper / Constantan)

DIN IEC 584-Part 1 temperature range: from -270 °C to 400 °C [1].

Suited for measurements in the −200 to 350 °C range. The positive conductor is made of copper, and the negative conductor is made of constantan. Often used as a differential measurement since only copper wire touches the probes. As both conductors are non-magnetic Type T thermocouples are a popular choice for applications such as Electrical Generators which contain strong magnetic fields. Type T thermocouples have a sensitivity of ~43 µV/°C [2].

Thermocouples are usually selected to ensure that the measuring equipment does not limit the range of temperatures that can be measured. Thermocouples with low sensitivity (B, R, and S) have a correspondingly lower resolution [2].

3.1.2.9 Applications

Thermocouples are most suitable for measuring over a large temperature range, up to 1800 K. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0 - 100 °C with 0.1 °C accuracy. For such applications, thermistors and RTDs are more suitable [2].

Steel Industry

Type B,S,R and K thermocouples are used extensively in the steel and iron industry to monitor temperatures and chemistry throughout the steel making process. Disposable, immersible, Type S thermocouples are regularly used in the electric arc furnace process to accurately measure the steel temperature before tapping. The cooling curve of a small steel sample can be analyzed and used to estimate the carbon content of molten steel [2].

Cement Industry

In modern precalciner systems a lot of thermocouples of type K are used to control the running process.

3.2 Pressure Measurement with Difference Pressure Transducer

A pressure meter measures two absolute pressures p1 and p2 and compares them with each other. The result of this measurement is called difference pressure (p1 – p2). The difference pressure meter can be composed of two measurement chambers which are separated hermetically by a membrane. The deflection of the membranes is proportional to the difference pressure [5].

3.2.1 Function

In practice the piezoresistive principle and inductive pressure measurement have become the most widely applied [12].

In the piezoresistive principle, the measuring element consist of silicon chip on which several resistors (usually four to six) are engraved. If the silicon chip is charged with pressure, it deforms only a few millimetre thus hysteresis behaviour. This deformation leads to changes in the resistance values, enabling the pressure applied to be calculated [12].

3.2.1.1 Ceramic Measuring Cell

The sensor element is a single-chamber ceramic measuring cell. It consists of a disk-shaped ceramic body with ceramic diaphragms on both sides. Depending on the acting pressures, the diaphragms move in or out and the measuring capacitances change. The difference of the individual capacitances is reciprocally proportional to the difference of the pressures [6].

3.2.1.2 Silicon Measuring Cell

The sensor element is a silicon plate with pressure sensitive resistors. The differential pressure to be measured is received via separating diaphragms and transmitted to the sensor element via incompressible oil (silicon or inert oil). The silicon plate moves according to the differential pressure. The values of the resistors change (piezoresistive principle) [6].

3.2.1.3 Facility for Conversion of Signal

The capacitance or resistance values are detected by the integrated electronics, processed in the microcomputer and converted into a 4 … 20 mA output signal. This output signal is proportional to the difference of the pressures. Precise, digital processing of measured data with maximum resolution ensures excellent data and accuracy [6].

3.3 Application for Measurement in a Precalcining System

Process Automation is of significance for producing high quality products at low costs. Especially the precalcining system with calciner and different stages of cyclones includes various process instrumentations such as pressure, temperature, flowmeter, and gas analyses instruments to reach a good heat and energy balance.

Measuring instruments for pressure and temperature are installed before and after the calciner to operate good combustion and calcining. Important reference values are pressure and temperature of gas and material at the kiln inlet chamber as well as at the hot gas duct for preheating the raw meal alternatively for the gas entry to the electric precipitator.

All measurement signals are routed to the process control system. Electronic and automatic data processing and certain definitive control actions evaluate the control functions. The software and program supervise the conditions of all input and output data to run the current process.

4 Assembly of Measurement

4.1 Hand-held Measuring Equipment

For the project measuring equipment by TESTO was used. TESTO is an international company which offers special solutions and products for measuring different parameters in industry. The main establishment is Germany, the Austrian establishment is registered as TESTO GmbH.

ÖMAG-Montananlagenbau GmbH bought a coordinated and comprehensive assortment of measuring equipment for the planned measuring system. All measuring articles with catalogue numbers are listed in 4.1.2 and 4.1.3 according to reference [4].

4.1.1 Annotation to Assembling of Measuring Equipment

The measuring equipment of TESTO is a module system and can be combined in different ways.

The control unit is the base of operations. It is a portable and robust measuring instrument with a user defined probe socket and built-in differential pressure probe. Convenient measuring functions such as timed/multi-point mean calculations and measurement programs can be put into execution and its results saved up to 250000 readings directly in the selected locations. The control unit saves parameters such as locations, measurement programs, limits, precision adjustment and system configuration.

It is possible to connect the control unit via the serial interface to the labtop/PC and prepare all measurement programs with the Software ComSoft3.

The control unit is connected with the data loggers. The communication between control unit and data logger takes place via the TESTO data bus which makes logger operating possible at different locations. The logger readings are output as a current signal (4-20 mA signal). The power box is used to supply power to the loggers and control unit.

The pressure and temperature probes transmit their signals to the data loggers which save the data according to the pre-established program.

An example of assembling of measuring equipment can be found in Figure 6.

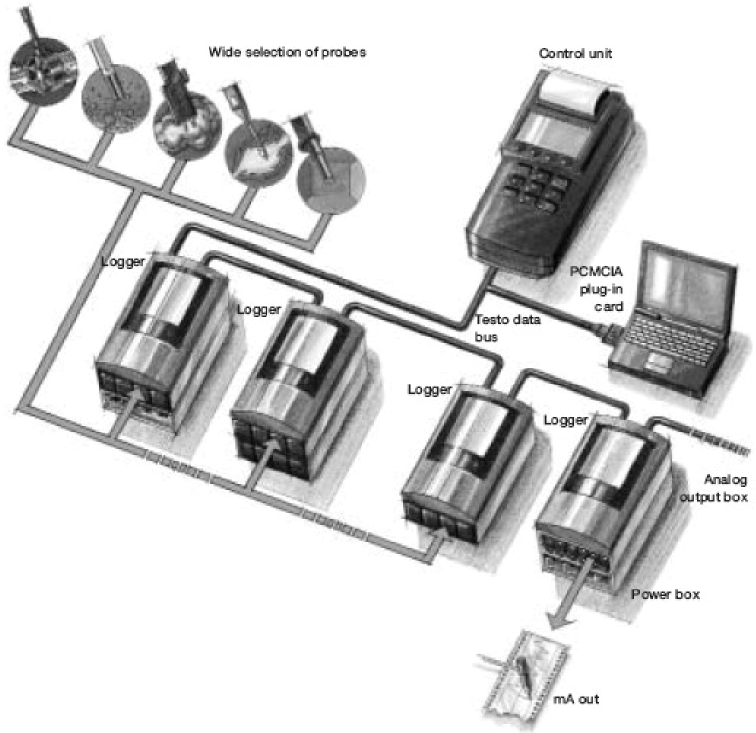

Figure 6: Assembly of Measuring Equipment of TESTO GmbH [21]

4.1.2 Main Parts

0563 0353 70 1 x Control Unit TESTO 350 and 454

The control unit displays measurement data and controls the measurement system. A built-in printer is included. Pressure measurement is possible between 40 and 200 hPa. Further features are a user defined probe socket and a connection for TESTO data bus incl. terminal plug. The control unit is able to run programmable measurements and has memory space for 250000 readings.

0577 4540 2 x Data Logger

The data logger measures and saves for maximum 250000 readings and can execute measurement programs independently. Any four user defined probe sockets can be connected. In order to be able to program the data logger and to read out the saved data, the Control Unit or data bus controller card (operated via personal computer and software) is needed. The Control Unit and data logger are connected with the aid of the data bus system.

0600 5893 3 x Thermocouple Type K (1 metre)

The thermocouple is of type K with plug-in measuring tip, 1030 mm long, flexible and has a diameter of 3 mm. It is used for high temperatures which range from -200 °C and + 1100 °C. The outer casting is made of “Inconel 2.4816”. Example see (Figure 7).

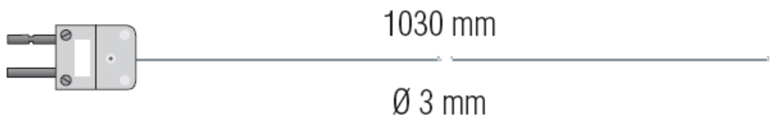

Figure 7: TESTO Measurement Systems: Plug-in measuring tip, 1030 mm long, flexible, for high temperatures, outer casting: Inconel 2.4816 [8]

0600 9999 3 x Thermocouple Type K (2 metres)

Description as 0600 5893 though nominal length is 2000 mm.

0638 1547 3 x Differential Pressure Probe

The differential pressure probe has a maximum range of 100 hPa and is used with silicone tubes. It will be used for measuring differential pressure. (Figure 8)

Figure 8: TESTO Measurement Systems: 4 to 20 mA interface for connection and intermittent power supply to transmitters [9]

056389451 1 x IR-Temperature-Measuring Instrument TESTO 845

The infrared temperature measuring instrument is able to measure surface temperatures of different materials.

4.1.3 Accessories

21TD0554 0445 4 x Silicone Tube

The silicon tube has an inner diameter of 4 mm and is added to the differential pressure meter. The total length of all four silicone tubes is 20 m.

0554 0007 3 x Electric/Voltage Cable for TESTO 454

The electric/voltage cable connects the control unit or the data logger with the differential pressure meter. The metering ranges are eligible between -10 V and +10 V, -1 V and 1 V and -20 mA and +20 mA.

0000 9999 5 x Adjustment Connection Cable

The adjustment connection cables enable lossless transmission of signals for temperature measurement.

These cables are custom-made products and of 10 m (2 x), 20 m (2 x) and 35 m (1 x) design with additional couplings.

0449 0042 1 x Connection Cable

This is a connection cable for the data bus with a length of 2 m.

Terminal plug for data bus

0430 0145 3 x Connection Cable

Connection cable for pressure probe with a length of 5 m.

21TS004090063 3 x Extension Cable

The extension cable makes it possible to elongate the connection cable 0430 0145.

0230 0033 1 x Data Bus Cable

The data bus cable has 8 poles and connects the data logger with another data logger, further the control unit with a data logger. Its total length is 30 m to bridge over long distance. Data transfer and import/export of programs are applicable.

0515 0097 3 x TESTO Rechargeable Battery Pack NiMH

Rechargeable batteries for the control unit and the two data loggers are used for operating the system without electric supply.

0554 1084 3 x Power Unit 230 V

The power unit recharges the batteries and operates the mains.

0554 1145 1 x Power Unit 230 V

Electrical supply for the TESTO data bus.

0600 5593 1 x Handle for plug-in measuring tip

The handle is provided for plugging in the measuring tip and enables the operator to work securely.

0409 0178 1 x RS232 Connection Cable

The RS232 connection cable establishes a connection between control unit or data logger and personal computer.

0554 0841 1 x Software ComSoft 3

Special software for data management, applicable for Windows 2000/XP or better. Database, analyses and graphics function, data analyses and trend curves are possible and included. The export of data to the program Microsoft Excel of Microsoft Office is very user-orientated and helpful for typical further treatment of data.

0516 0410 System Case

The system case is made of aluminium for measuring instruments, probes and accessories.

4.2 Methodology

For getting data about pressure drops of cyclones, riser ducts and other components of the precalcining system as well as temperature ratios of gas and materials of different stages, an assembly of contemporaneous measurement was suggested.

In general measurement of pressure or temperature is operated continuously by permanent installed measuring equipment on the one hand. On the other hand additional hand measurement is made during audits for instance whereby special samples are drawn.

For running a normal process at NUH CIMENTO SANAYAI A.S measuring points for pressure and temperature are mostly foreseen at riser ducts of the precalcining system. Due to new design and geometry numerous data of physical properties are of interest.

Therefore additional measurement points are established to achieve more accurate information about the behaviour of the elements. Among the existing installed equipment at the riser ducts, which indicate the values before the gas enters the cyclones, auxiliary holes for this project are foreseen for bringing in hand measuring equipment. The preheater tower itself is subdivided into measuring sections which will be specified as units.

A special feature of this measuring method is that the created units enable a nearly self-contained system that means, according to a cyclone all inputs and outputs can be considered as complete. Detailed retrieving data for particular analyses of simultaneous conditions is possible, as well as in-depth analyses of geometric subdivisions.

Processing of data obtained at the same time allows comparability and exactitude of stages, exemplifying pressure loss of entry and outlet of gas flow of a cyclone. Data of conventional measuring mostly shows higher deviation because of single measured and recorded data with time difference.

In the field study of the reference plant measuring points are developed for the following positions:

- raw meal inlets: temperature of material
- first part of riser ducts, under splash box of meal pipe: pressure and temperature of gas
- elbow of riser ducts; before entry of cyclone: pressure and temperature of gas
- meal pipes, before flaps: temperature of material
- calciner, after discharging of gas flow, position is equivalent to riser duct of cyclone C4: pressure and temperature of gas
- calciner: before entry of gas flow, position is equivalent to tertiary duct: pressure and temperature of gas
- kiln inlet: pressure and temperature of gas

- top cyclones: crossover to id-fans: pressure and temperature of gas

4.2.1 Preliminary Form of Planned Measuring

In general the measurement is planned for a period of 2 weeks and is split up into 3 complete measuring cycles. Each cycle is subdivided in a period of two days for measurement and a subsequent period of maximum two days for collecting and first consideration of all data.

In each cycle data of temperature, pressure, gas velocity, gas analyses, surface temperature, chemical analyses of fuel, raw meal and clinker, feeding rate of fuel and raw meal, fan speed, energy consumption and some more will be recorded for further company-internal consideration.

It is very important to keep all processes constant during one measuring cycle. It would be possible to modify process parameters after a measuring cycle (e.g. raw meal feed, tertiary air distribution or any modification which would be of interest).

If there are considerable fluctuations in the process a waiting time of 1 to 2 days between the measurements is recommendable.

In each measuring cycle so-called “units” with a defined amount of measuring points are the basis for collecting the measurement data. A measurement unit comprise of a riser duct, mealpipes and a cyclone normally.

The classification of these units is stated below as well as identified in flow sheets.

A unit consists of existing and new measurement points; new measuring points related to temperature and pressure data will be collected continuously from data loggers. In the meantime surface temperature of cyclones, riser ducts and pipes will be measured by infrared-measurement equipment. Data from MIS – Management Information System – will be recorded automatically continuously for the complete core unit. The MIS is a data base which is recording measuring data of the current process in a cement company.

Time for measurement per unit is foreseen with approximately 30 minutes. After measuring a unit approximately 1 hour will be needed for arrangement of next unit. The measuring interval for data loggers will be minimum 2 seconds.

Existing measuring points should be calibrated in advance.

During measuring and installation of equipment shock blowers near measuring points could be a risk of accident, especially near measuring points NEW 1, NEW 2, NEW 15, NEW 16 (Table 2). In case of danger shock blowers have to be shut down.

4.3 Measuring Points at Site

4.3.1 Classification of Measuring Points

The preheater of kiln line III of NUH CIMENTO SANAYAI A.S. features existing measuring points for pressure and temperature as shown in Table 1.

Table 1: List of Existing Measuring Points (p, T)

Pressure	Postion		Temperature	Position	
330C1AB_PZ1	duct	ID1	330C1AB_TZ1	duct	ID1
330C2_PZ1	riser duct	RC1	330C2_TZ1	riser duct	RC1
330C3_PZ1	riser duct	RC2	330C3_TZ1	riser duct	RC2
330C4_PZ1	riser duct	RC3	330C4_TZ1	riser duct	RC3
330CB03_PZ1	riser duct	RC4	330CB03_TZ1	riser duct	RC4
330CB01_PZ1	riser duct	RK4	330CB01_TZ1	riser duct	RK4
330K1AB_PZ1	duct	ID2	330K1AB_TZ1	duct	ID2
330K2_PZ1	riser duct	RK1	330K2_TZ1	riser duct	RK1
330K3_PZ1	riser duct	RK2	330K3_TZ1	riser duct	RK2
330K4_PZ1	riser duct	RK3	330K4_TZ1	riser duct	RK3
331TA_PZ1	tertiary air duct	TA1	331TA_TZ1	tertiary air duct	TA1
			330ID01_TZ3	duct	ID1
			330ID02_TZ3	duct	ID2
			330KI01_TZ1	kiln inlet	K0

For this project new measuring points for pressure and temperature are denoted as shown in Table 2. They are appointed after the new holes which are drilled into available ducts und vary only in notation of use. Pressure and temperature holes are located at close quarters.

Table 2: List of New Measuring Points for Pressure and Temperature

Pressure	Temperature	Position	
NEW 1	NEW 1	kiln inlet	KI0
NEW 2	NEW 2	riser duct	RK3
NEW 3	NEW 3	riser duct	RK3
NEW 4	NEW 4	riser duct	RK2
NEW 5	NEW 5	riser duct	RK1
NEW 6	NEW 6	riser duct	RK1
NEW 7	NEW 7	riser duct	RC3
NEW 8	NEW 8	riser duct	RC2
NEW 9	NEW 9	riser duct	RC1
NEW 10	NEW 10	riser duct	RC1
NEW 11	NEW 11	swirl pot	C1A
NEW 12	NEW 12	swirl pot	C1B
NEW 13	NEW 13	swirl pot	K1A
NEW 14	NEW 14	swirl pot	K1B
+ existing	NEW 15	riser duct	RK4
	NEW 16	tertiary air duct	TA1

Contin. Table 2: List of New Measuring Points for Pressure and Temperature

	NEW M1	meal pipe	MPK4
	NEW M2	meal pipe	MPC4
	NEW M3	meal pipe	MPC3
	NEW M4	meal pipe	MPK4
	NEW M5	meal pipe	MPC2
	NEW M6	meal pipe	MPK2
	NEW M7	meal pipe	MPC1B
	NEW M8	meal pipe	MPC1A
	NEW M9	meal pipe	MPK1A
	NEW M10	meal pipe	MPK1B
	NEW M11	meal pipe	MK0
	NEW M12	meal pipe	MC0
	+ existing		

The position of the existing and new measuring points for pressure and temperature are reported in the enclosed flow sheets, Figure 9 till Figure 11.

4.3.2 Classification of Units

The implementation of units is necessary to achieve self-contained systems. The units consist of existing and new measuring points. In Table 3 all points are differentiated to units and its signals for the data loggers of hand measuring. Further distinction is given with kiln string and calciner string.

Unit 1 deals with the kiln inlet chamber and riser duct K4.

Units 2, 3, 6, 7 and 8 concentrate on the cyclones.

Units 4 and 9 are subdivided into 4A, 4B and 9A, 9B because of the twin cyclones design.

Units 5 and 10 consist of existing measuring equipment, no hand measuring is necessary.

The only possibility to measure contemporaneous the whole preheater by hand if a dozen of data loggers and hundreds of meters of connection cables are available. But due to the high costs for surplus equipment, a more simple form was chosen. All units are designed to arrange the measuring equipment in such a way, that the long distances between the measuring points can be overcome without too much complexity and expenses.

A graphical demonstration can be seen in the inserted flow sheets, cut into three parts:

Overview of Measuring Points: Units 1 – 10 (Figure 9 or rather Flow Sheet 1/3)

Units 1 -5 (Figure 10 or rather Flow Sheet 2/3)

Units 6 – 10 (Figure 11 or rather Flow Sheet 3/3)

Table 3: Classification of Units

Kiln String			
Unit	**No. of Signals**	**Measuring Point for Pressure**	**Measuring Point for Temperature**
1	6	NEW 1 = 1b	NEW 1 = 1b
		NEW 2	NEW 2
			NEW M1
			NEW M3
			330KI01_TZ1
		330CB01_PZ1	330CB01_TZ1
2	8	NEW 2	NEW 2
		NEW 3	NEW 3
		NEW 4	NEW 4
			NEW M4
			NEW M5
		330K4_PZ1	330K4_TZ1
3	7	NEW 4	NEW 4
		NEW 5	NEW 5
			NEW M6
			NEW M7
			NEW M8
		330K3_PZ1	330K3_TZ1
4A	7 (+1)	NEW 5	NEW 5
		NEW 6	NEW 6
		NEW 13	NEW 13
			NEW M9
			NEW M10
			NEW M11
		330K1AB_PZ1	330K1AB_TZ1
		330K2_PZ1	330K2_TZ1
4B	7 (+1)	NEW 5	NEW 5
		NEW 6	NEW 6
		NEW 14	NEW 14
			NEW M9
			NEW M10
			NEW M11
		330K1AB_PZ1	330K1AB_TZ1
		330K2_PZ1	330K2_TZ1
5		330K1AB_PZ1	330K1AB_TZ1
		330ID02_PZ3	330ID01_TZ3

Calciner String			
Unit	**No. of Signals**	**Measuring Point for Pressure**	**Measuring Point for Temperature**
6	6	NEW 7	NEW 7
			NEW M1
			NEW M2
			NEW 15
			NEW 16
		330CB03_PZ1	330CB03_TZ1
7	6	NEW 7	NEW 7
		NEW 8	NEW 8
			NEW M3
			NEW M4
		330C4_PZ1	330C4_TZ1
8	6	NEW 8	NEW 8
		NEW 9	NEW 9
			NEW M5
			NEW M6
		330C3_PZ1	330C3_TZ1
9A	8 (+2)	NEW 9	NEW 9
		NEW 10	NEW 10
		NEW 11	NEW 11
			NEW M7
			NEW M8
		330C2_PZ1	330C2_TZ1
		330C1AB_PZ1	330C1AB_TZ1
9A	8 (+2)	NEW 9	NEW 9
		NEW 10	NEW 10
		NEW 11	NEW 11
			NEW M9
			NEW M10
		330C2_PZ1	330C2_TZ1
		330C1AB_PZ1	330C1AB_TZ1
9B	8 (+2)	NEW 9	NEW 9
		NEW 10	NEW 10
		NEW 12	NEW 12
			NEW M7
			NEW M8
		330C2_PZ1	330C2_TZ1
		330C1AB_PZ1	330C1AB_TZ1

Cont. Table 3: Classification of Units

9B	8 (+2)	NEW 9	NEW 9
		NEW 10	NEW 10
		NEW 12	NEW 12
			NEW M9
			NEW M10
		330C2_PZ1	330C2_TZ1
		330C1AB_PZ1	330C1AB_TZ1
10		330C1AB_PZ1	330C1AB_TZ1
		330ID01_PZ3	330ID02_TZ3

4.4 Measurement of Surface Temperatures

Surface Temperatures are measured with IR-Temperature-Measuring Instrument TESTO 845. A special measuring plan is developed to reconstruct all results in future. All measuring points are drawn in detailed engineering drawings of the precalciner system and remain by reason of data volume in the backup files of ÖMAG-Montananlagenbau GmbH.

4.4.1 Measuring System for Cyclones

Each cyclone is splitted in upper part same as top of cyclone and its conical exterior shell. Because of circular surface a reference point is introduced at the upper area of the inlet of the riser duct which leads into the cyclone. At the top of the cyclone four measuring points for measuring surface temperature are marked at equally distributed points. At the exterior shell another four points in four different heights are used to get an amount of various surface temperatures.

4.4.2 Measuring System for Riser Ducts

Riser ducts are also divided into fourths and measured at the lower and upper part of the riser duct.

4.4.3 Measuring System for Meal Pipes

Meal pipes have four measuring points; two before and two after the flap. The only difference is that the meal pipes are not divided into fourths but into upper and lower halves instead.

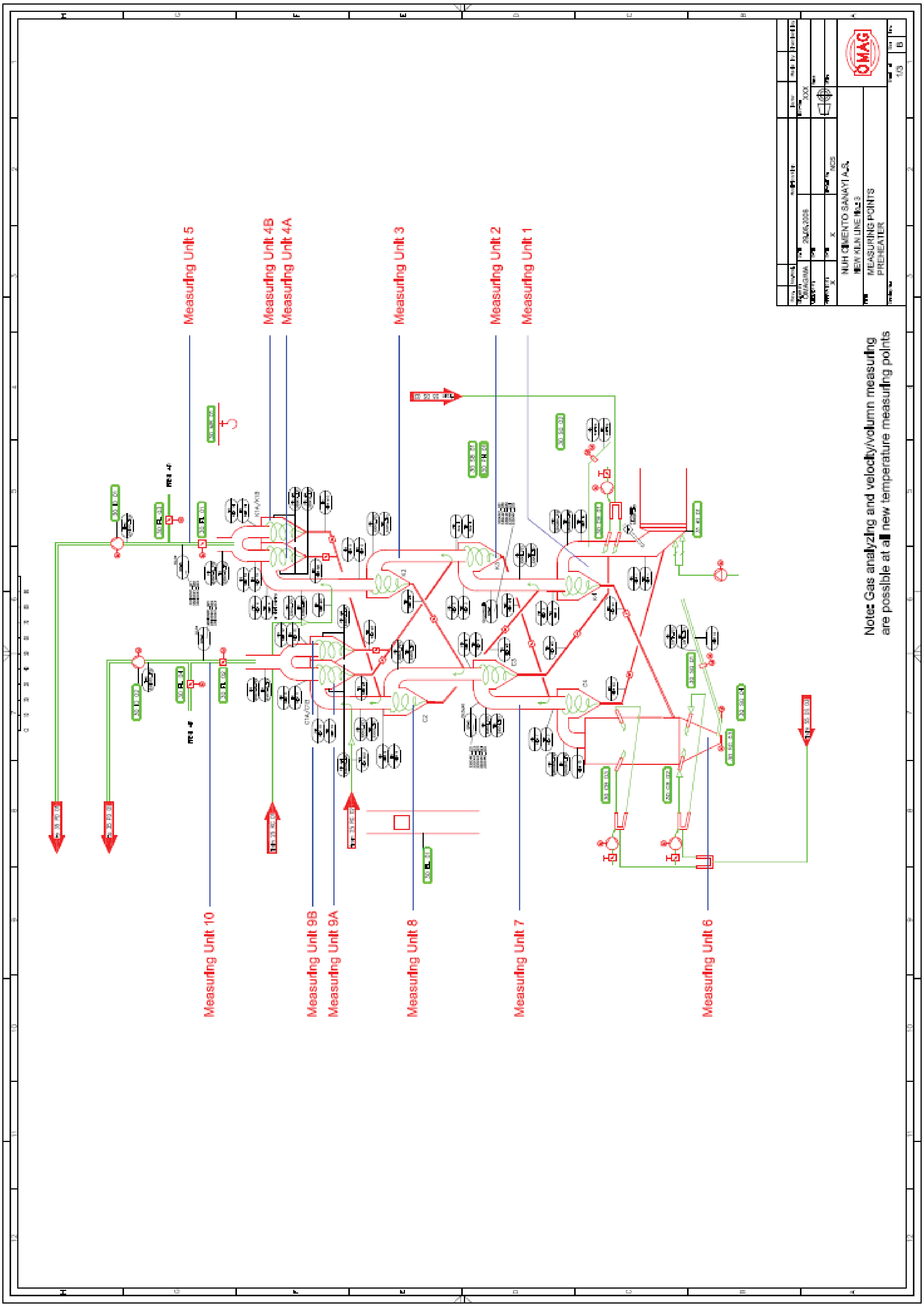

Figure 9: Overview of Measuring Points: Units 1 – 10; Flow Sheet

[Flow Sheet als A4 raus und in A3-Fomat einfügen und falten!]

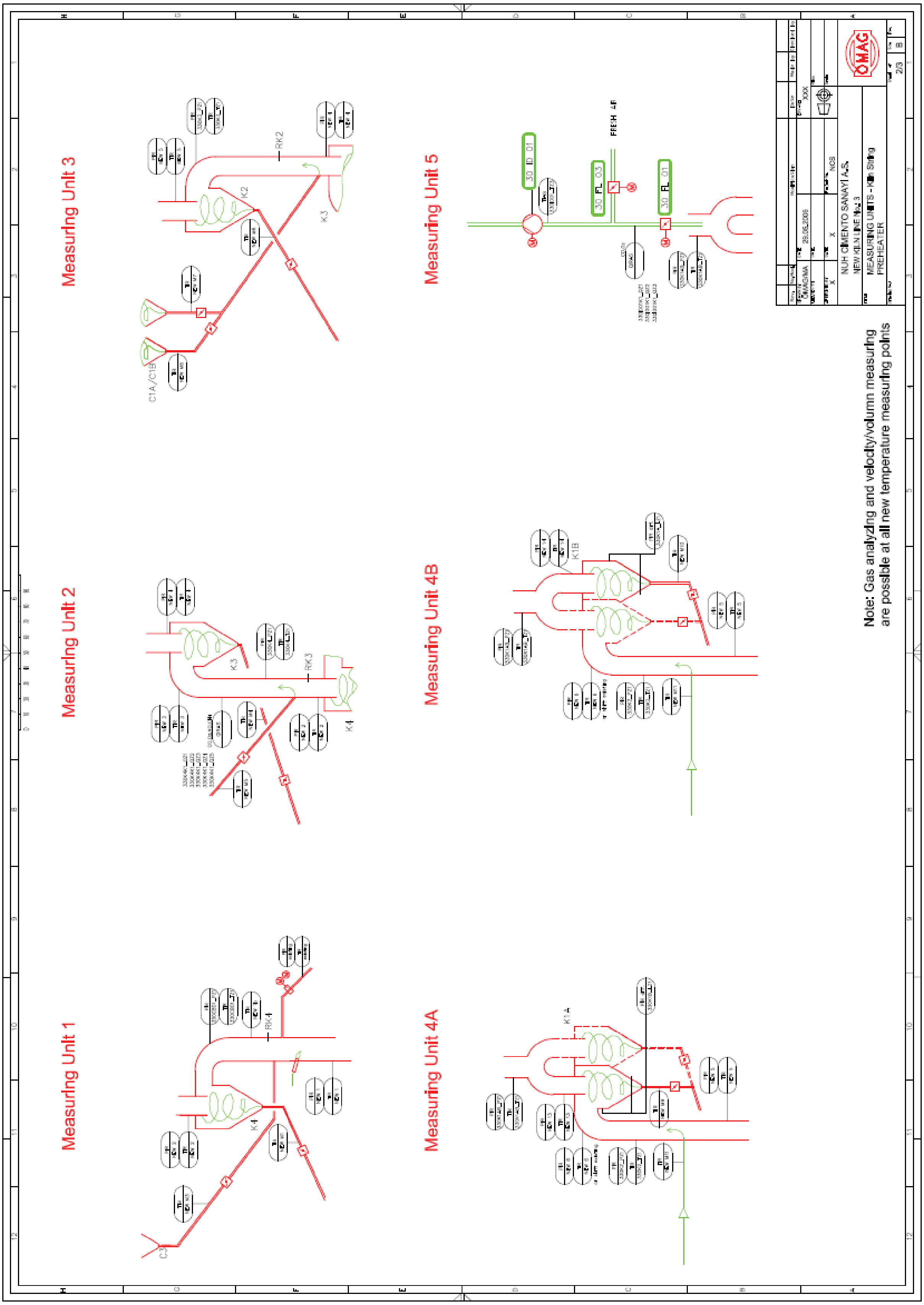

Figure 10: Units 1- 5; Flow Sheet

[Flow Sheet als A4 raus und in A3-Fomat eingefügt und gefaltet]

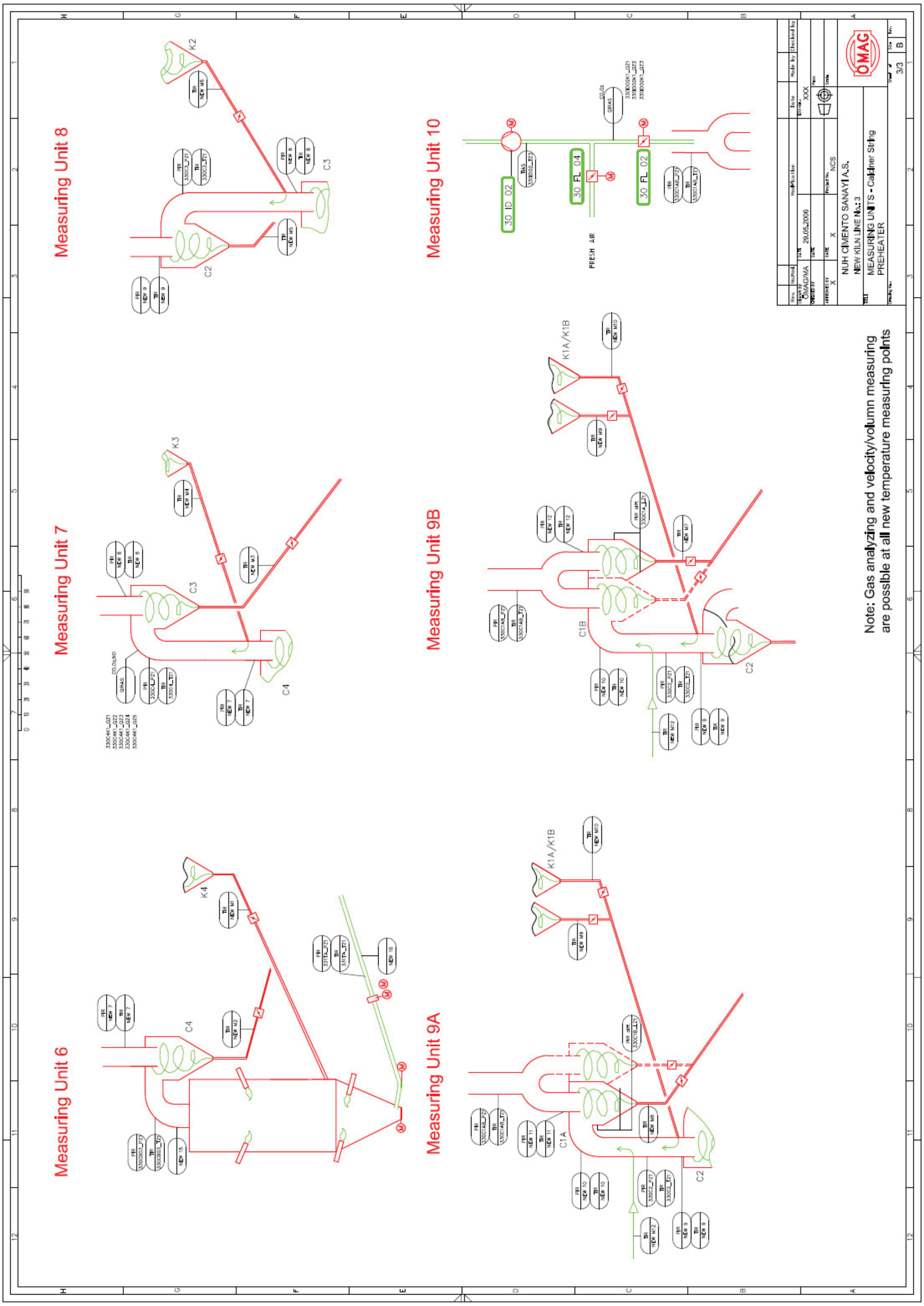

Figure 11: Units 6 – 10; Flow Sheet

[Flow Sheet als A4 raus und in A3-Fomat eingefügt und gefaltet]

5 Execution of Measurement at Site

At the beginning of the project a period of two weeks was planned at the plant of NUH CIMENTO SANAYAI A.S. In fact of several circumstances, such as different results of existing thermocouples and adequate hand measuring equipment, changes in execution of measurement and also further measuring, the time at plant was elongated up to 5 weeks.

The measurement work was executed according to the following plan:

- ➔ Get familiar with site conditions
- ➔ Final preparation of new measuring points
- ➔ Test measuring
- ➔ Measuring of all defined units
- ➔ Collecting and sorting of all measured data
- ➔ Additional hand measurement for surface temperature
- ➔ First analyses of measured data
- ➔ Collecting data of the MIS - Management Information System

5.1 Prearrangement

NUH CIMENTO SANAYAI A.S prepared all necessary and additional measuring points for kiln line III in advance. Therefore new holes and flanges were installed.

After starting the measuring project in Turkey and getting familiar with site conditions, all measuring points were controlled for its correct installation. The required staff was instructed into the measuring procedure. Initial skill adaptation training was essential to figure out subsidence collection of data from the MIS – Management Information System.

5.2 Test Measurement

At the beginning a test measurement was started to check if the planned period for arrangement of a unit is correct and if the first results of the measurement are correct and useful.

Therefore test measurements – in this case Unit 3 – had been started. During the tests several problems occurred. The planned assembling of Unit 3 was defined by one hour, but it was not possible to abide on time. Three workers were needed instead to prepare one measuring unit. Due to the complexity of the measuring equipment and the sensibility of the electrical cables, the duration of this procedure took about eight hours.

Results of the first testing period showed that temperature values deviated from the indicated values of the MIS – Management Information System. Another testing cycle delivered similar results. For this reason NUH CIMENTO SANAYAI A.S. decided to start additional measuring tests to verify the values of the MIS. Following equipment was used: the hand-held measuring equipment BEAMEX TC 305 with thermocouple Type K. According to the fact that the position of the existing measuring points are at close quarters, simultaneous temperature measurements were accomplished by entering the pressure holes. Both thermocouples from TESTO and BEAMEX were implemented at same time. The detailed single values of TESTO, BEAMEX and CCR can be seen in Appendix.

The average values of gas temperatures of the existing thermocouples deviated from those of the hand measuring equipment of TESTO as it can be seen in Table 4 and Table 5. A graphical presentation is shown in Figure 12 and Figure 13.

Table 4: Comparison of Average Gas Temperatures between TESTO and CCR of Calciner String

Comparison of Average Gas Temperatures between TESTO and CCR of Calciner String							
Pos.	14.7. TESTO	14.7. CCR	**Delta T1**	18.7. TESTO	18.7. CCR	**Delta T2**	Delta T1-T2
[1]	[℃]	[℃]	**[℃]**	[℃]	[℃]	**[℃]**	
ID	348,67	326,00	**22,67**				
RC1	375,71	347,13	**28,58**				
RC2	577,50	536,77	**40,73**				
RC3	708,57	640,65	**67,92**	712,00	703,16	**8,84**	59,08
RC4	888,33	874,84	**13,49**				

Table 5: Comparison of Average Gas Temperatures between TESTO and CCR of Kiln String

Comparison of Average Gas Temperatures between TESTO and CCR of Kiln String							
Pos.	14.7. TESTO	14.7. CCR	**Delta T1**	18.7. TESTO	18.7. CCR	**Delta T2**	Delta T1-T2
[1]	[℃]	[℃]	**[℃]**	[℃]	[℃]	**[℃]**	
ID		211,00					
RK1	242,00	222,25	**19,75**				
RK2	493,67	461,17	**32,50**				
RK3	629,18	587,13	**42,06**	628,80	616,02	**12,78**	29,27
RK4	822,75	751,60	**71,15**	815,29	793,75	**21,54**	49,61

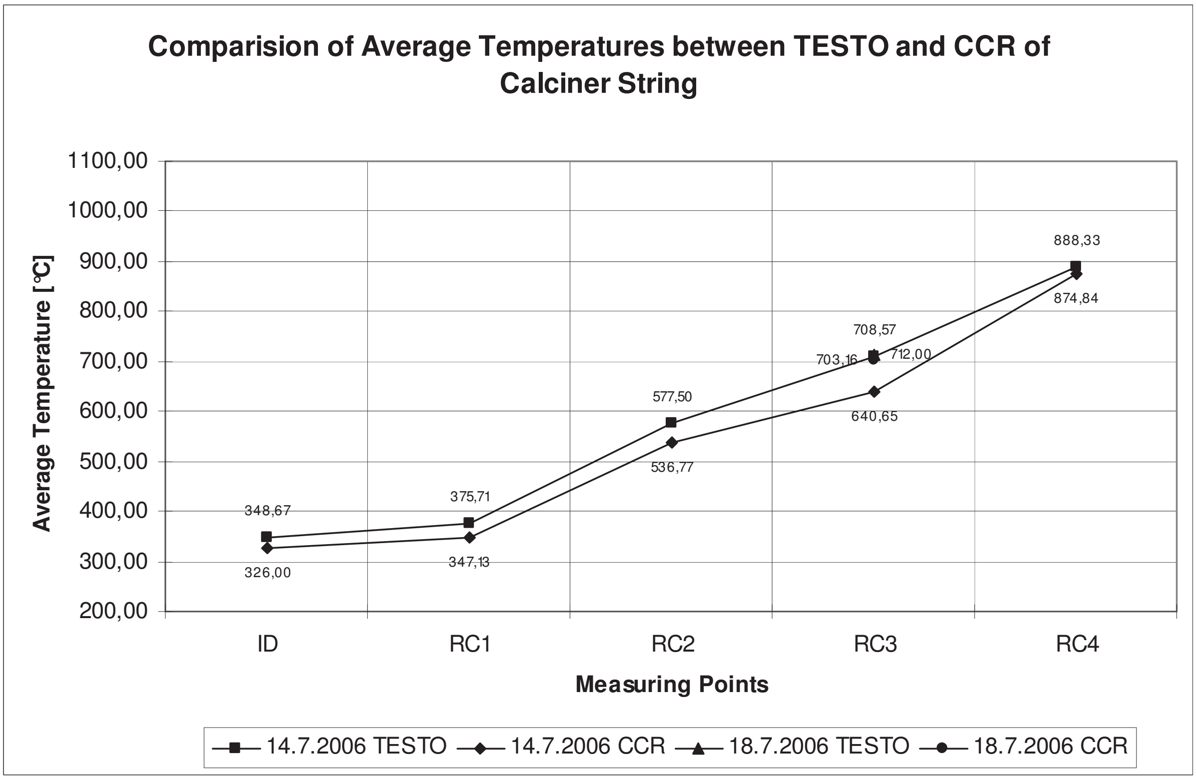

Figure 12: Comparison of Average Gas Temperatures between TESTO and CCR of Calciner String

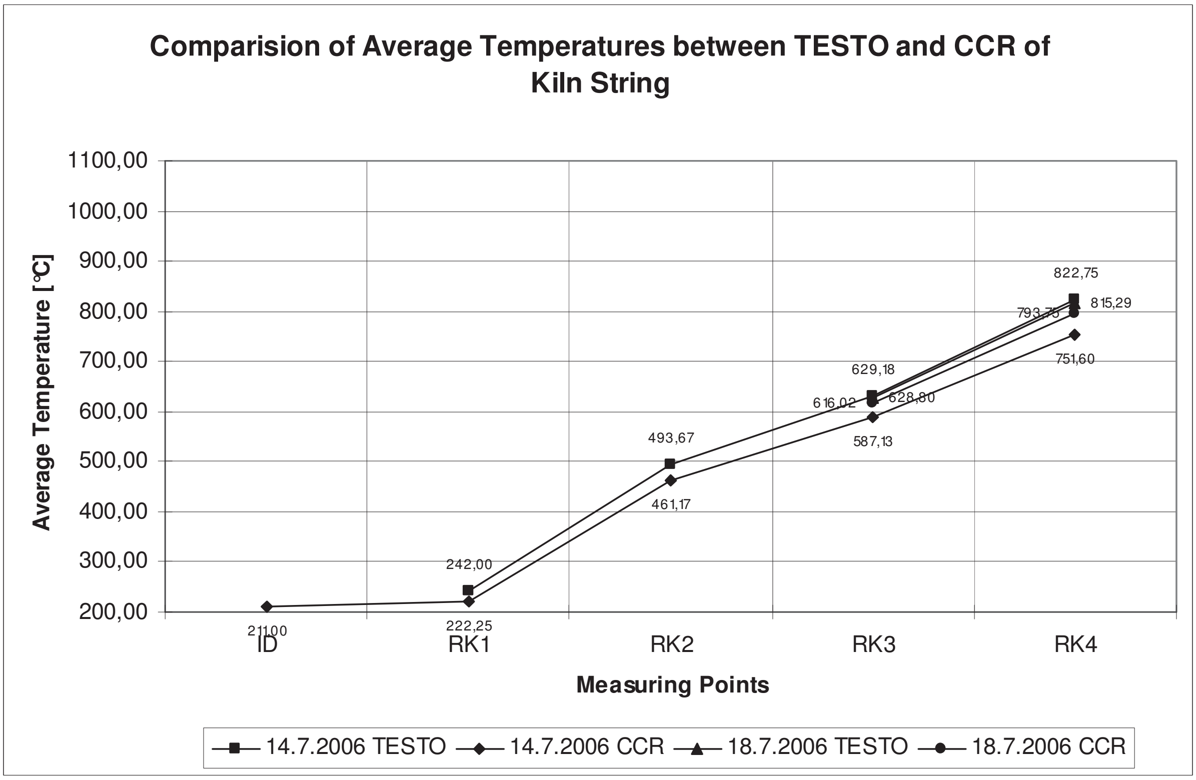

Figure 13: Comparison of Average Gas Temperatures between TESTO and CCR of Kiln String

Adequate transmitters and its software for MIS have been products of SIEMENS. Originally used thermocouples also made by SIEMENS were replaced with thermocouples from different manufacturers which caused deviated values of temperature. The exchanged thermocouples including the partial new installed connection cables effected inaccuracies. A lot of thermocouples did not have cold junction compensation boxes. These boxes correct the temperature values by means of a thermocouple Type Pt100 and appropriate software. A list of used thermocouples can be seen in Table 6.

Table 6: List of Used Thermocouples and Transmitters, NUH CIMENTO SANAYAI A.S., 17.7.2006

17.7.2006 List of Used Thermocouples and Transmitters								
Pos.	**Thermocouple**			**Name**	**Seriel No.**	**Type**	**Comments**	**Transmitter**
RK1	**330**	**K2**	**TZ1**	Reckmann GmbH	D-58137	1xNiCr-Ni Typ K	Hagen R58	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
ID	**330**	**K1A/B**	**TZ1**	Reckmann GmbH	D-58137	1xNiCr-Ni Typ K	Hagen R58	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
ID	**330**	**C1A/B**	**TZ1**	Reckmann GmbH	D-58137	1xNiCr-Ni Typ K	Hagen R58	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RK2	**330**	**K3**	**TZ1**	Elimko	06-2678	1xNiCr-Ni Typ K	TC01-1K2N22-120-PY	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RC1	**330**	**C2**	**TZ1**	Elimko	06-2670	1xNiCr-Ni Typ K	TC01-1K2N22-120-PY	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RC2	**330**	**C3**	**TZ1**	Meter	1807/06	1xNiCr-Ni Typ K	Kod: 220101/KS/200V22/821,821	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RC3	**330**	**C4**	**TZ1**	Elimko	06/2683	1xNiCr-Ni Typ K	TC01-1K2N22-120-PY	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RK3	**330**	**K4**	**TZ1**	Meter	1798/06	1xNiCr-Ni Typ K	Kod: 220101/KS/200V22/821,821	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RK4	**330**	**CB01**	**TZ1**	Elimko	06/2688	1xNiCr-Ni Typ K	TC01-1K2N22-120-PY	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RC4	**330**	**CB03**	**TZ1**	Meter	1800/06	1xNiCr-Ni Typ K	Kod: 220101/KS/200V22/821,821	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
RC4	**330**	**CB03**	**TZ2**	Elimko	----	1xNiCr-Ni Typ K	TC01-1K2N22-120-PY	Elimko
RC4	**330**	**CB03**	**TZ3**	Elimko	----	1xNiCr-Ni Typ K	TC01-1K2N22-120-PY	Elimko
TA-Duct	**331**	**TA**	**TZ1**	Elimko	----	1xNiCr-Ni Typ K	TC01-1K2N22-120-PY	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
TA-Duct	**331**	**TA**	**TZ2**	Siemens	----	1xNiCr-Ni Typ K	7MC2000-2FC06-Z R58 406620/020	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
ID	**330**	**ID01**	**TZ1**	Siemens	----	1xNiCr-Ni Typ K	7MC2000-2FC06-Z R58 406620/020	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
ID	**330**	**ID02**	**TZ1**	Siemens	----	1xNiCr-Ni Typ K	7MC2000-2FC06-Z R58 406620/020	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
KH	**432**	**KH01**	**TZ1**	Meter	1808/06	1xNiCr-Ni Typ K	Kod: 220101/KS/200V22/821,821	Siemens SITRANS T (7NG3020, 7NG3022 Ex)
KI	**330**	**KI01**	**TZ1**	Siemens	----	Pyrometer	C71450-AC-180-A017	----

Due to the fact that every single exchanged thermocouple indicated various values of temperature, it was tried to modify hardware and software. Finally modifying was cancelled because costs and efforts were too high.

Originally developed measuring methodology (chapter 4.2.) was insufficient at that point by reason that later calculation would have led to imprecise results. Hereupon test measuring had been stopped and a modified measuring methodology was necessary.

5.3 Modified Measuring Methodology

Primarily planned measuring methodology was intended to get values from existing and new measurement points simultaneously. The new modified and expanded measuring procedure is different in following points: Additional measuring of five minutes will be done at all existing measuring points for temperature, in fact before and after the real measurement of a unit.

This extra hand measurement of temperature will be accomplished by insertion of thermocouple next to the existing measuring point, in this case the pressure hole.

Aim is to adjust approximated temperature values of existing thermocouples upwards or downwards on the basis of subsequent calculation. If a temperature value of a thermocouple is 50 ℃ too low, the value will be corrected exactly with this mentioned numerical average value – taken from the average results of the additional measurements - for instance and can be incorporated for the final analyses.

After modifying the concept it was possible to start measuring all units.

5.4 Execution of Measuring

Basically it was planned to measure two units per day but some practice was necessary to keep the time schedule.

After laying the cables and positioning control unit and data loggers all pressure probes and thermocouples were prepared for use. Next step was checking functional capability. Then the control room was informed about removing the pressure probe next to the existing thermocouple to execute a five minute hand measurement for temperature.

It was very important that measuring equipment of TESTO was not exposed to high temperature too long. Therefore all thermocouples and pressure probes were inserted to measurement holes shortly before starting measuring a unit. In general a measuring cycle took twenty minutes. Connection and extension cables were very sensitive and permanent control was needed.

After finishing a unit second measurement according to 5.3 with duration of five minutes was done. These steps completed all required data and another arrangement of next unit could be performed.

For the whole calculation data of MIS – Management Information System with all needed tags had to be exported.

5.5 Measuring Data

Two different kinds of measuring data were collected: on the one hand data of hand-held measuring equipment of TESTO, and on the other hand data of the MIS – Management Information System.

The original idea of retrieving data of defined time periods and tags from the MIS – Management Information System failed because of its complexity and above all high expenditure of time. It was necessary to get additional data of decisive tags to control a smooth general cement production. Therefore data of all required tags of the MIS – Management Information System was downloaded from 8 until 18 o'clock, in a time slice of a second.

Finally the overall amount of data grew up to approximately 38 million single values. The next step was to take out all required data (approximately 1 million single values) for subsequent calculation and analyses. This process was very time-consuming and could not be done at site.

5.6 Measuring Problems

Two main problems occurred during the measurements: Kiln stops forced to measurement breaks of minimum six hours, because refractory heat influenced temperature for a long time period. It is to consider that these stops were independent from measuring. Furthermore extension and connection cables caused many defective contacts. Therefore the measurements had to be repeated.

5.7 Negative Influences during Measuring

It must be pointed out that gas and material temperatures are intermixing. Geometry of ducts and cyclones lead to different current flow conditions of gas and material. Furthermore technical reasons like heat transfer between gas and material are responsible in a couple of cases that material and gas temperatures diverge. Because of the instability of gas flow it is hard to determine the exact value of temperature and pressure at a given point and therefore it is necessary to take average values for following analyses and calculations in more detail.

Considering to the point that heated material can accumulate on thermocouples after a longer time period, the duration of use must be kept quite short. In practice accumulation did not occur very often.

Another negative influence on getting exact measuring results could appear by laying connection and extension cables close to hot structural parts of the preheater tower.

6 Calculation of Heat Balance of Precalcining System and Further Significant Values

6.1 Calculation of Heat Balance of Precalcining System

NOTA BENE:

This heat balance is not calculated as standard heat balance in cement industry and does not show specific heat consumption of normally 700 up to 720 kcal/kg clinker for this cement plant. Below-mentioned calculation does not include heat consumption and loss of rotary kiln, clinker cooler and further smaller components. Calculations only refer to the preheating and precalcining tower!

Stated below heat balance of the tower is displayed with the following limits:

- ➔ Transition kiln inlet chamber – rotary kiln
- ➔ Transition tertiary air duct – calciner
- ➔ Transition tertiary air duct – riser duct RK4
- ➔ Transition hot gas air ducts – id fans
- ➔ Transition raw meal conveyor – raw meal inlet at riser duct

Tables belonging to heat balance: Table 7, Table 8, Table 9, Table 10

Table 7: Results of Input and Output of Heat Balance of Precalcining System

Input	Q [kJ/h]	Q [kcal/kg_cli]
Q[B1a, B1b, B2]	475.455.622	407,32
Q[Ic, Ik]	33.638.096	28,82
Q[Tlc]	182.234.815	137,00
Q[Tlk]	0	0,00
Q[K]	273.092.958	233,10
Q[air B1a, B1b, B2]	1.465.905	1,26
Q[alkaline cond.]	35.427.577	30,35
Total	**978.022.899**	**837,85**

Output	Q [kJ/h]	Q [kcal/kg_cli]
Q[Fc]	105.671.115	90,53
Q[Fk]	73.231.665	62,74
Q[material]	244.705.432	209,63
Q[calc.]	530.666.481	454,62
Q[l]	23.731.482	20,33
Total	**978.022.899**	**837,85**

Table 8: General Heat Balance and Its Declaration

Heat Balance	
Input	
Q[B1a, B1b, B2]	Heat of Calciner and Secondary Burners
Q[Ic, Ik]	Heat of Raw Meal Feed
Q[TIc]	Heat of Gas of Tertiary Air Duct at Entry
Q[TIk]	Heat of Gas of Tertiary Air Duct at Entry
Q[K]	Heat of Gas of Kiln at Entry
Q[air B1a, B1b, B2]	Heat of Primary Air for Burners and False Air
Q[alkaline cond.]	Heat of Alkaline Condensation
Output	
Q[Fc]	Heat of Exhaust Gas of Calciner String
Q[Fk]	Heat of Exhaust Gas of Kiln String
Q[material]	Heat of Precalcined Material
Q[calc.]	Heat of Calcining Process
Q[l]	Heat Loss through Surface Area

Table 9: General Data of Production and Coal Consumption

General Data		
Raw Meal Feed	460,0	[t/h]
Clinker Production	278,792	[t/h]
	6.691	[t/d]
Coal Consumption		
Main Burner	13,6	[t/h]
Secondary Burner	3,0	[t/h]
Calciner Burner	14,6	[t/h]
Total Coal	31,2	[t/h]

Table 10: Calculation of Heat Balance of Precalcing System

Q[Ic, Ik]

Formula	Q = cp*m*T		
	[kJ/h] = [kJ/kgK]*[kg/h]*[K]		
	cp = 0,973 + 0,00016705*T		(for raw meal)
	[kJ/kgK]		
Data for Calculation	cp	0,9854	[kJ/kgK]
	m	460.000	[kg/h]
	T	74,21	[°C]
Results	Q	33.638.096	[kJ/h]
		8.033.937	[kcal/h]
		28,82	**[kcal/kg_cli]**

Q[material]

Formula	Q = cp*m*T		
	[kJ/h] = [kJ/kgK]*[kg/h]*[K]		
	cp = 0,76761 + 0,00022442*T		(for precalcined meal)
	[kJ/kgK]		
Data for Calculation	cp	0,955	[kJ/kgK]
	m	278.792	[kg/h]
	T	835,54	[°C]
	Factor	1,1	[kg/kg_cli]
Results	Q	244.705.432	[kJ/h]
		5.844.410	[kcal/h]
		209,63	**[kcal/kg_cli]**

Q[B1a, B1b, B2]

Formula	Q = Hu*m		
	[kJ/h] = [kJ/kg]*[kg/h]		
Data for Calculation			
	Hu coal	6.452	[kcal/kg]
	Hu coal	27.015	[kJ/kg]
	Consumption of Coal	17.600	[kg/h]
Results	Q	475.455.622	[kJ/h]
		113.555.200	[kcal/h]
		407,31	**[kcal/kg_cli]**

Q[l]

Formula	$Q = \alpha * A * \Delta T$		
	$\alpha = 7{,}14 * v^{0{,}78}$		
	1 Ws = 1 J		
	1 h = 3600s		
Data for Calculation	from Table Surface Temperatures and Heat Loss		
	Heat Transfer Coefficient α	16,82	[W/m²K]
	Outside Temperature	27	[°C]
	Approx. Wind speed	3	[m/s]
	Surface Area	8.004	[m²]
Results	Q	6.592,08	[kW]
		23.731.482	[kJ/h]
		5.667.896	[kcal/h]
		20,33	**[kcal/kg_cli]**

Q[calc.]

Formula of Strassen	Q (Clinker) = 2,22*Al2O3 + 5,86*H2O + 6,48*MgO + 7,646* CaO - 5,116*SiO2 - 0,59 Fe2O3		
	Clinker Analyses		
Data for Calculation	Elements	Factor	[%]
	Al203 (+)	2,22	4,24
	MgO (+)	6,48	1,10
	CaO (+)	7,646	66,56
	H2O (+)	5,86	1,60
	SiO2 (-)	5,116	21,90
	Fe2O3 (-)	0,59	4,11
Intermediate Results	Elements		
	Al203 (+)	9,41	[kcal/kg_cli]
	MgO (+)	7,13	[kcal/kg_cli]
	CaO (+)	508,92	[kcal/kg_cli]
	H2O (+)	9,38	[kcal/kg_cli]
	SiO2 (-)	112,04	[kcal/kg_cli]
	Fe2O3 (-)	2,42	[kcal/kg_cli]
Intermediate Results	Endothermic (+)	534,83	[kcal/kg_cli]
	Exothermic (-)	114,47	[kcal/kg_cli]
	Total	420,37	[kcal/kg_cli]
	Endothermic (+) (for approx. 85% decarbonisation)	454,61	[kcal/kg_cli]
Results	Q	530.666.481	[kJ/h]
		126.741.457	[kcal/h]
		454,61	**[kcal/kg_cli]**

Q[Fc,Fk]

Formula

Q = V*cp*T

[kJ/h] = [Nm³/h]*[kJ/Nm³K]*[K]

n/n=V/V=T/T

[RPM/RPM] = ((m³/s)/(m³/s)] = [°C/°C]

Vo = Vn*(T0+T)/T0*po/(p0+pstat)

Vn = Vo*T0/(T0+T)*(p0+pstat)/p0

Vo…operating m³/h,Vn…norm Nm³/h

Data for Calculation	cp	acc. Table 20	[kJ/Nm³K]
	T0	273,15	[K]
	p0	1.013,25	[mbar]

Fan Performance	Volume Flow		142,2	[m³/s]
	Speed		990	[1/min]
	Temperature		370	[°C]
	Statical Pressure		- 85	[mbar]
From MIS	RPM - Fan Kiln String		95	[%]
	RPM - Fan Calciner String		87	[%]
Calculation		[RPM]	[m³/s]	
		990	142,20	
		940,50	135,09	
		[RPM]	[m³/s]	
		990	142,20	
		861,30	123,71	
			[°C]	[mbar]
From Measurement	330C1AB_TZ1		347,49	-77,13
	330C1AB_TZ1		353,72	-76,89
	330C1AB_TZ1		358,91	-76,48
	330C1AB_TZ1		355,48	-76,56
	Average Values		353,90	-76,77
	330K1AB_TZ1		211,54	-77,70
	330K1AB_TZ1		216,06	-77,74
	Average Values		213,80	-77,72
Calculation	Volume Flow - Fc		54,39	[Nm³/s]
	Volume Flow - Fc		195.797	[Nm³/h]
	Volume Flow - Fc		0,702	[Nm³/kg_cli]
	Volume Flow - Fk		64,07	[Nm³/s]
	Volume Flow - Fk		230.656	[Nm³/h]
	Volume Flow - Fk		0,827	[Nm³/kg_cli]
Results	Heat of Gas of Calciner String			
	T		353,9	[°C]
	Cp		1,525	[kJ/Nm³K]
	Q		105.671.115	[kJ/h]
			25.237.915	[kcal/h]
			90,53	**[kcal/kg_cli]**
	Heat of Gas of Kiln String			
	T		213,8	[°C]
	Cp		1,485	[kJ/Nm³K]
	Q		73.231.665	[kJ/h]
			17.490.247	[kcal/h]
			62,74	**[kcal/kg_cli]**

Q[Tlk]

Data	Tertiary air duct to riser duct K4 was closed		
Results	Q	**0,00**	**[kcal/kg_cli]**

Q[Tlc]

Formula	Q = V*cp*T		
	[kJ/h] = [Nm³/h]*[kJ/Nm³K]*[K]		
Data for Calculation	cp	1,409	[kJ/Nm³K]
	Recuperation Air to Calciner Burners	0,430	[Nm³/kg_cli]
	Recuperation Air to Calciner Burners	119.880	[Nm³/h]
	Recuperation Air to Secondary Burner (duct was closed)	0,000	[Nm³/kg_cli]
From Measurement	NEW 16	946,77	[°C]
Results	Q	159.920.348	[kJ/h]
		38.194.494	[kcal/h]
		137,00	**[kcal/kg_cli]**

Q[air B1a, B1b, B2]

Formula	Q = V*cp*T		
	[kJ/h] = [Nm³/h]*[kJ/Nm³K]*[K]		
Data for Calculation	cp	1,307	[kJ/Nm³K]
	Outside Temperature	27	[°C]
	Recuperation Air to Calciner Burner	0,490	[Nm³/kg_cli]
	Primary Air (approx. 10%)	0,049	[Nm³/kg_cli]
	False Air (approx.)	0,100	[Nm³/kg_cli]
	Total Air	0,149	[Nm³/kg_cli]
	Total Air	41.540	[Nm³/h]
Results	Q	1.465.905	[kJ/h]
	Q	350.109	[kcal]
	Q	**1,26**	**[kcal/kg_cli]**

Q[K]

Formula	Q = V*cp*T		
	[kJ/h] = [Nm³/h]*[kJ/Nm³K]*[K]		
Data for Calculation	cp (accord. Table 20)	1,690	[kJ/Nm³K]
	Exhaust Gas of Rotary Kiln	0,550	[Nm³/kg_cli]
	Exhaust Gas of Rotary Kiln	153.335	[Nm³/h]
	T (approx.)	1.050	[°C]
Results	Q	272.092.958	[kJ/h]
		64.985.182	[kcal/h]
		233,10	**[kcal/kg_cli]**

Q[alkaline cond.]

Data from ÖMAG	Exhaust Gas of Rotary Kiln	127,08	[kJ/kg_cli]
Results	Q	35.427.577	[kJ/h]
		8.461.327	[kcal]
		30,35	**[kcal/kg_cli]**

6.2 Calculation of Emerging Volatile Components and Clinker Factor

Table 11: Calculation of Emerging Volatile Components and Clinker Factor

MM_Molar Mass	**[kg/kmol]**	**RM_Raw Meal**	**[%]**
Al	26,98	CaO	43,32
Ca	40,08	MgO	0,76
Mg	24,31	Al2O3	2,64
C	12,01		
O2	31,99		
CaO	56,08		
MgO	40,30		
CO2	44,01		
H2O	18,01		
Al2O3	101,93		

Calculation - CO2

CO2 from CaCO3	0,3400	[%%]	=(MM_CO2/MM_CaO)*(RM_CaO/100)
CO2 from MgCO3	0,0083	[%%]	=(MM_CO2/MM_MgO)*(RM_MgO/100)
Total CO2	0,3483	[%%]	= CO2 from CaCO3 + CO2 from MgCO3

Calculation - H2O

H2O from Caolinite	0,0093	[%%]	= (2*MM_H2O/MM_Al2O3)*(RM_Al2O3/100)

Loss on ignition

LOI	0,3576	[%%]	= H2O from Caolinite + Total CO2

Ash in Clinker

Ash in Coal	14,25	[%]	
Coal consumption	31200	[kg/h]	
Clinker production	278792	[kg/h]	
Ash in clinker	0,016	[kg/kg_cli]	= 14,25/100*31200/278792

Clinker Factor

Clinker Factor	1,541	[-]	= 1/(1-LOI) – Ash in Clinker

The theoretical clinker factor correlates to the requirement of dry raw meal for 1 kg clinker. The real ratio of about 1,65 considers the circulation dust in the system and the moisture content in the the raw meal

Emerging volatile components from decarbonisation of raw meal and dehydration of water are accounted for calculation stated in Table 11. Loss on ignition (LOI) and clinker factor represent the common known results.

6.3 Calculation of Net Calorific Value of Used Fuel

Table 12 contains the fuel analyses of coal and corresponds to the used coal during measurement. According calculation of net calorific value is shown in Table 13.

Table 12: Fuel Analyses of Coal and Net Calorific Value

Analyses Fuel	Coal	
C	68,41	[%]
H_2	4,28	[%]
S	0,73	[%]
O_2	9,02	[%]
H_2O	1,33	[%]
N_2	1,98	[%]
Ash	14,25	[%]
Total	100,00	[%]

Net Calorific Value	**27015,28**	(kJ/kg)
	6452,18	(kcal/kg)

Table 13: Calculation of Net Calorific Value

Elements	**[%][%]**	**Factor**	**Result**	**Sign**
C	0,6841	34800	23806,68	+
H_2	0,0428	93800	4014,64	+
S	0,0073	10460	76,36	+
O_2	0,0902	10800	974,16	-
H_2O	0,0133	2450	32,59	-
N_2	0,0198	6280	124,34	+

6.4 Calculation of Exhaust Gas Analyses

Subsequent list and calculation of exhaust gas in normal cubic meter per kilogram from combustion of coal can be found in Table 14. According exhaust gas analyses as percentage is stated in Table 15, fresh air gas analyses in Table 16, and gas analyses from decarbonisation of raw meal in Table 17. Last-mentioned tables serve for calculation of real mix gas analyses in the upper part of the preheater tower, Table 18.

The norm volume of exhaust gas from coal combustion, decarbonisation and false air is shown in Table 19. According calculated list (source of supply by ÖMAG-Montananlagenbau GmbH) of average specific heat capacity for the calculated real mix gas analyse, Table 20, act as basis for Chapter 7.8, more precisely for calculation of heat in combined unit 9A and 9B.

Table 14: Calculation of Exhaust Gas from Combustion of Coal

Analyse Fuel	Coal	
C	68,41	[%]
H_2	4,28	[%]
S	0,73	[%]
O_2	9,02	[%]
H_2O	1,33	[%]
N_2	1,98	[%]
Ash	14,25	[%]
Total	100,00	[%]
Excess Air	1,15	[Nm³/nm³]
Norm Volume	22,414	[Nm³/kmol]
Molecular Weights		
C	12,010	[kg/kmol]
H_2	2,016	[kg/kmol]
S	32,060	[kg/kmol]
O_2	32,000	[kg/kmol]
H_2O	18,016	[kg/kmol]
N_2	28,020	[kg/kmol]
Specific Oxygen Demand		
C -> CO_2	1,866	[Nm³/kg]
H_2 -> H_2O	5,559	[Nm³/kg]
S -> SO_2	0,699	[Nm³/kg]
O_2 -> O_2	0,700	[Nm³/kg]
Stoichiometric Oxygen Demand	1,457	[Nm³/kg]
Stoichiometric Fresh Air Demand	6,936	[Nm³/kg]
Combustion Air	7,976	[Nm³/kg]
Exhaust Gas		
CO_2	1,277	[Nm³/kg]
H_2O	0,492	[Nm³/kg]
N_2	6,317	[Nm³/kg]
O_2	0,218	[Nm³/kg]
SO_2	0,005	[Nm³/kg]
Total	8,310	[Nm³/kg]

Table 15: Exhaust Gas Analyses from Combustion of Coal

Exhaust Gas Analyses		
CO_2	15,36	[%]
H_2O	5,93	[%]
N_2	76,02	[%]
O_2	2,63	[%]
SO_2	0,06	[%]
Total	100,00	[%]

Table 16: Fresh Air Gas Analyses

Fresh Air Analyses		
CO_2	0,04	[%]
H_2O	0	[%]
N_2	78	[%]
O_2	21	[%]
SO_2	0	[%]
Others	0,96	[%]
Total	100,00	[%]

Table 17: Decarbonisation Gas Analyses

Decarbonisation Analyses		
CO_2	100,00	[%]
H_2O	0	[%]
N_2	0	[%]
O_2	0	[%]
SO_2	0	[%]
Total	100,00	[%]

Table 18: Real Mix Gas Analyses

Real Mix Gas Analyses		
CO_2	32,48	[%]
H_2O	4,19	[%]
N_2	59,75	[%]
O_2	3,46	[%]
SO_2	0,04	[%]
Others	0,07	[%]
Total	100,00	[%]

Table 19: Norm Volume of Exhaust Gas from Coal Combustion, Decarbonisation and False Air

Volume [Exhaust Gas from Coal, Decarbonisation and False Air]			
Data for Calculation	Raw Meal Feed	460000	[kg/h]
	Clinker Production	278792	[kg/h]
	Total Coal	31200	[kg/h]
	Clinker Factor	1,54	[-]
	V	8,31	[Nm³/kg coal]
	m	0,11	[kgCoal/kg_cli]
	Rho of CO_2	1,96	[kg/m³]
Results	**V [Coal]**	**0,93**	**[Nm³/kg_cli]**
	V [CO_2]	**0,28**	**[Nm³/kg_cli]**
	V [False Air]	**0,10**	**[Nm³/kg_cli]**
Total	**V [Total]**	**1,31**	**[Nm³/kg_cli]**

Table 20: Average Specific Heat Capacity [kJ/nm³K]

Average Specific Heat Capacity [kJ/nm³ K]						
1	2	3	4	5	6	7
T [℃]	CO2	H2O	N2	O2	SO2	Mixgas
0	1,631	1,491	1,302	1,310	1,711	1,416
100	1,725	1,499	1,304	1,319	1,822	1,449
200	1,812	1,516	1,309	1,336	1,908	1,481
300	1,884	1,541	1,316	1,357	1,981	1,511
400	1,947	1,562	1,327	1,380	2,045	1,539
500	2,014	1,583	1,336	1,400	2,101	1,568
600	2,064	1,608	1,348	1,419	2,151	1,593
700	2,110	1,633	1,361	1,436	2,193	1,618
800	2,150	1,658	1,373	1,453	2,230	1,639
900	2,190	1,689	1,386	1,465	2,263	1,662
1000	2,219	1,712	1,398	1,480	2,291	1,680
1100	2,253	1,742	1,411	1,491	2,318	1,700
1200	2,279	1,767	1,424	1,503	2,341	1,718
1300	2,303	1,792	1,432	1,511	2,364	1,732
1400	2,325	1,817	1,444	1,522	2,384	1,748
1500	2,346	1,838	1,453	1,532	2,403	1,761
1600	2,370	1,860	1,459	1,538	2,421	1,774
1700	2,385	1,881	1,467	1,547	2,437	1,785
1800	2,400	1,902	1,476	1,555	2,453	1,796
1900	2,414	1,924	1,482	1,563	2,468	1,805
2000	2,428	1,947	1,488	1,572	2,482	1,815
2100	2,445	1,964	1,494	1,578	2,495	1,825
2200	2,462	1,981	1,501	1,584	2,508	1,835
2300	2,475	1,998	1,507	1,590	2,520	1,844
2400	2,487	2,015	1,513	1,597	2,532	1,853
2500	2,500	2,031	1,519	1,603	2,544	1,861

7 Results

7.1 General Results of Pressure and Temperature

Table 21: General Results of Pressure and Temperature

Date	Unit	No. of Signals	Measuring Point	Data Logger	Channel	Average Pressure [mbar]	Standard Deviation	Measuring Point	Data Logger	Channel	Average Temperature [°C]	Standard Deviation
04.08.2006	1	6	NEW 1 = 1b	25	4	-7,05	0,23	NEW 1 = 1b	25	3	811,86	3,17
			NEW 2	25	2	-17,00	1,19	NEW 2	25	1	753,84	6,01
								NEW M1	28	1	833,40	1,23
								NEW M3	28	2	708,08	1,86
								330KI01_TZ1			1031,87	9,71
			330CB01_PZ1			-7,06	0,23	330CB01_TZ1			811,86	3,98
07.08.2006	2	8	NEW 2	25	2	-16,70	1,09	NEW 2	25	1	758,95	6,00
			NEW 3	28	2	-22,61	0,92	NEW 3	28	1	665,33	1,78
			NEW 4	28	4	-29,92	0,96	NEW 4	28	3	648,61	1,00
								NEW M4	25	4	644,60	0,66
								NEW M5	25	3	551,06	26,37
			330K4_PZ1			-20,15	0,79	330K4_TZ1			617,52	3,79
01.08.2006	3	7	NEW 4	28	2	-29,66	1,14	NEW 4	28	1	649,40	0,91
			NEW 5	25	2	-46,56	1,33	NEW 5	25	3	415,87	3,29
								NEW M6	25	1	470,23	0,67
								NEW M7	28	3	364,63	0,62
								NEW M8	28	4	364,55	0,74
			330K3_PZ1			-37,46	0,96	330K3_TZ1			564,23	3,97
01.08.2006	4A	7 (+1)	NEW 5	25	2	-46,72	1,56	NEW 5	25	1	416,30	5,74
			NEW 6	28	2	-58,38	1,42	NEW 6	28	1	241,40	1,28
			NEW 13	28	4	-72,59	1,28	NEW 13	28	3	235,79	0,85
								NEW M9	25	3	247,93	1,60
								NEW M10	25	4	235,19	0,83
								NEW M11			74,21	0,21
			330K1AB_PZ1			-77,70	0,95	330K1AB_TZ1			211,54	1,86
			330K2_PZ1			-50,91	1,31	330K2_TZ1			245,99	2,03
01.08.2006	4B	7 (+1)	NEW 5	25	2	-46,69	1,73	NEW 5	25	1	413,69	4,99
			NEW 6	28	2	-58,44	1,37	NEW 6	28	1	241,62	1,38
			NEW 14	28	4	-72,77	1,27	NEW 14	28	3	240,73	0,74
								NEW M9	25	3	247,28	1,31
								NEW M10	25	4	235,22	0,77
								NEW M11			74,21	0,21
			330K1AB_PZ1			-77,74	0,86	330K1AB_TZ1			216,06	1,78
			330K2_PZ1			-51,03	1,26	330K2_TZ1			238,04	1,77

Contin. Table 21: General Results of Pressure and Temperature

04.08.2006	6	6	NEW 7	25	2	-20,27	1,08	NEW 7	25	1	904,49	4,79
								NEW M1	28	2	890,74	6,50
								NEW M2	28	1	835,54	0,91
								NEW 15	25	3	888,97	6,78
								NEW 16	28	3	946,77	1,37
			330CB03_PZ1			-13,58	0,39	330CB03_TZ1			882,03	7,58
03.08.2006	7	6	NEW 7	28	2	-20,05	1,10	NEW 7	28	1	912,13	5,74
			NEW 8	25	2	-32,65	1,16	NEW 8	25	1	742,28	2,60
								NEW M3	28	3	716,49	2,41
								NEW M4	25	3	651,52	0,53
			330C4_PZ1			-24,58	0,22	330C4_TZ1			794,67	5,75
03.08.2006	8	6	NEW 8	25	2	-33,05	1,22	NEW 8	25	1	735,73	3,35
			NEW 9	28	2	-45,44	1,40	NEW 9	28	1	517,26	4,98
								NEW M5	25	3	566,42	1,01
								NEW M6	28	3	471,00	0,88
			330C3_PZ1			-38,33	1,08	330C3_TZ1			533,23	1,77
02.08.2006	9A	8 (+2)	NEW 9	28	2	-45,79	1,36	NEW 9	28	1	518,11	3,43
			NEW 10	25	2	-65,75	1,11	NEW 10	25	1	373,66	0,87
			NEW 11	25	4	-71,19	1,17	NEW 11	25	3	365,61	0,73
								NEW M9	28	3	237,81	0,66
								NEW M10	28	4	247,60	0,92
			330C2_PZ1			-51,53	1,48	330C2_TZ1			347,49	1,66
			330C1AB_PZ1			-77,13	0,78	330C1AB_TZ1			321,52	0,75
02.08.2006	9A	8 (+2)	NEW 9	28	2	-45,40	1,32	NEW 9	28	1	514,50	4,75
			NEW 10	25	2	-65,36	1,10	NEW 10	25	1	374,14	1,06
			NEW 11	25	4	-70,89	1,14	NEW 11	25	3	366,52	0,72
								NEW M7	28	4	365,79	0,70
								NEW M8	28	3	359,34	0,70
			330C2_PZ1			-50,96	1,38	330C2_TZ1			353,72	2,02
			330C1AB_PZ1			-76,89	0,67	330C1AB_TZ1			316,10	2,56
02.08.2006	9B	8 (+2)	NEW 9	28	2	-44,93	1,32	NEW 9	28	1	512,38	4,41
			NEW 10	25	2	-65,05	1,12	NEW 10	25	1	374,05	1,25
			NEW 12	25	4	-72,17	1,22	NEW 12	25	3	366,78	0,90
								NEW M7	28	4	365,70	0,85
								NEW M8	28	3	357,94	1,32
			330C2_PZ1			-50,27	2,01	330C2_TZ1			358,91	0,40
			330C1AB_PZ1			-76,48	0,80	330C1AB_TZ1			318,33	2,11
02.08.2006	9B	8 (+2)	NEW 9	28	2	-45,13	1,32	NEW 9	28	1	508,06	4,47
			NEW 10	25	2	-65,12	1,04	NEW 10	25	1	372,92	0,77
			NEW 12	25	4	-72,19	1,16	NEW 12	25	3	366,04	0,66
								NEW M9	28	3	236,31	0,61
								NEW M10	28	4	238,28	0,92
			330C2_PZ1			-50,67	1,41	330C2_TZ1			355,48	0,52
			330C1AB_PZ1			-76,56	0,63	330C1AB_TZ1			318,91	2,08

7.2 Pressure

All measuring results of pressure of kiln string are listed in Table 22, those of calciner string in Table 23.

Figure 14 till Figure 17 illustrate the total pressure loss of Units 1, 2, 3, 4A, 4B, 6, 7, 8, 9A, 9B.

Pressure loss of single units can be seen in Figure 18 up to Figure 27.

7.2.1 Results of Kiln String

Table 22: Kiln String – Average Pressure and Delta Pressure

Kiln String						
Date	**Unit**	**Signals**	**Pressure**	**Average pressure [mbar]**	**Standard Deviation**	**Delta Pressure [mbar]**
04.08.2006	1	6	NEW 1 = 1b	-7,05	0,23	-9,96
			NEW 2	-17,00	1,19	
07.08.2006	2	8	NEW 2	-16,70	1,09	-3,46
			330K4_PZ1	-20,15	0,79	-2,46
			NEW 3	-22,61	0,92	-7,31
			NEW 4	-29,92	0,96	
01.08.2006	3	7	NEW 4	-29,66	1,14	-7,79
			330K3_PZ1	-37,46	0,96	-9,10
			NEW 5	-46,56	1,33	
01.08.2006	4A	7 (+1)	NEW 5	-46,72	1,56	-4,19
			330K2_PZ1	-50,91	1,31	-7,47
			NEW 6	-58,38	1,42	-14,21
			NEW 13	-72,59	1,28	-5,11
			330K1AB_PZ1	-77,70	0,95	
01.08.2006	4B	7 (+1)	NEW 5	-46,69	1,73	-4,34
			330K2_PZ1	-51,03	1,26	-7,41
			NEW 6	-58,44	1,37	-14,33
			NEW 14	-72,77	1,27	-4,98
			330K1AB_PZ1	-77,74	0,86	

7.2.2 Results of Calciner String

Table 23: Calciner String – Average Pressure and Delta Pressure

Calciner String						
Date	**Unit**	**Signals**	**Pressure**	**Average pressure [mbar]**	**Standard Deviation**	**Delta Pressure [mbar]**
04.08.2006	6	6	330CB03_PZ1	-13,58	0,39	-6,69
			NEW 7	-20,27	1,08	
03.08.2006	7	6	NEW 7	-20,05	1,10	-4,53
			330C4_PZ1	-24,58	0,22	-8,07
			NEW 8	-32,65	1,16	
03.08.2006	8	6	NEW 8	-33,05	1,22	-5,28
			330C3_PZ1	-38,33	1,08	-7,12
			NEW 9	-45,44	1,40	
02.08.2006	9A	8 (+2)	NEW 9	-45,79	1,36	-5,74
			330C2_PZ1	-51,53	1,48	-14,22
			NEW 10	-65,75	1,11	-5,45
			NEW 11	-71,19	1,17	-5,93
			330C1AB_PZ1	-77,13	0,78	
02.08.2006	9B	8 (+2)	NEW 9	-44,93	1,32	-5,34
			330C2_PZ1	-50,27	2,01	-14,77
			NEW 10	-65,05	1,12	-7,12
			NEW 12	-72,17	1,22	-4,31
			330C1AB_PZ1	-76,48	0,80	

7.2.3 Total Pressure Loss

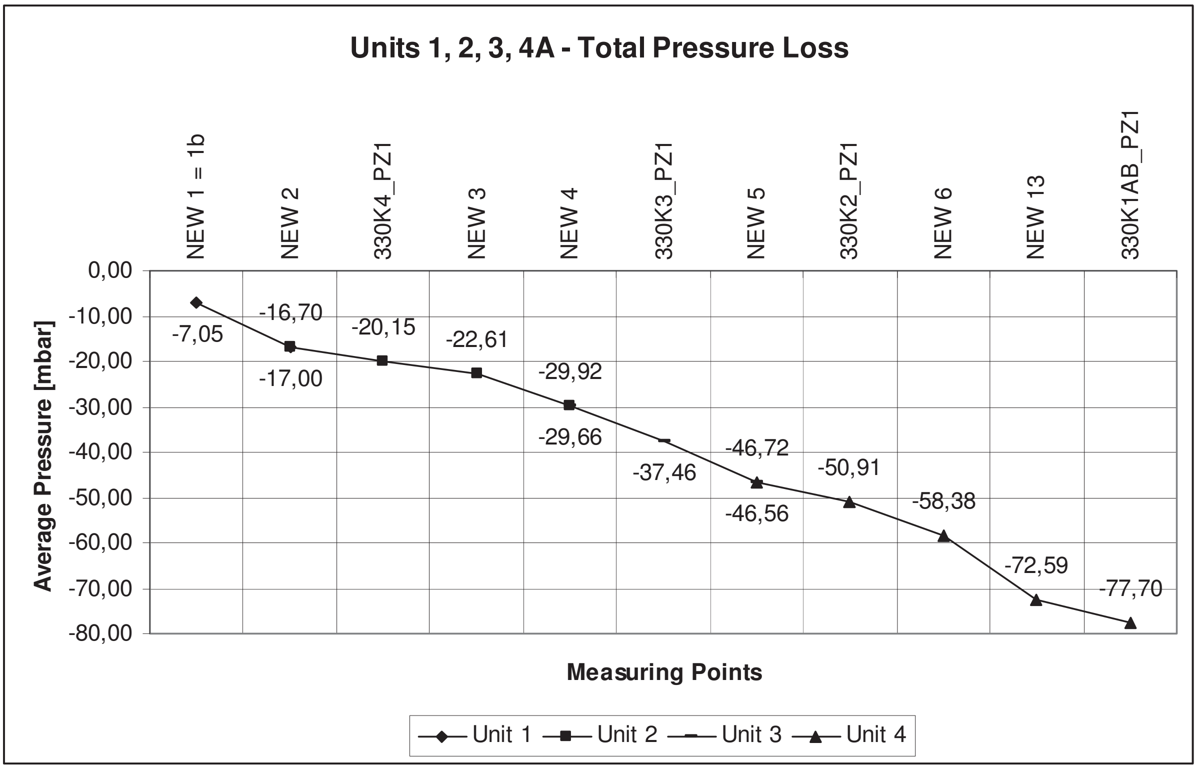

Figure 14: Units 1, 2, 3, 4A – Total Pressure Loss

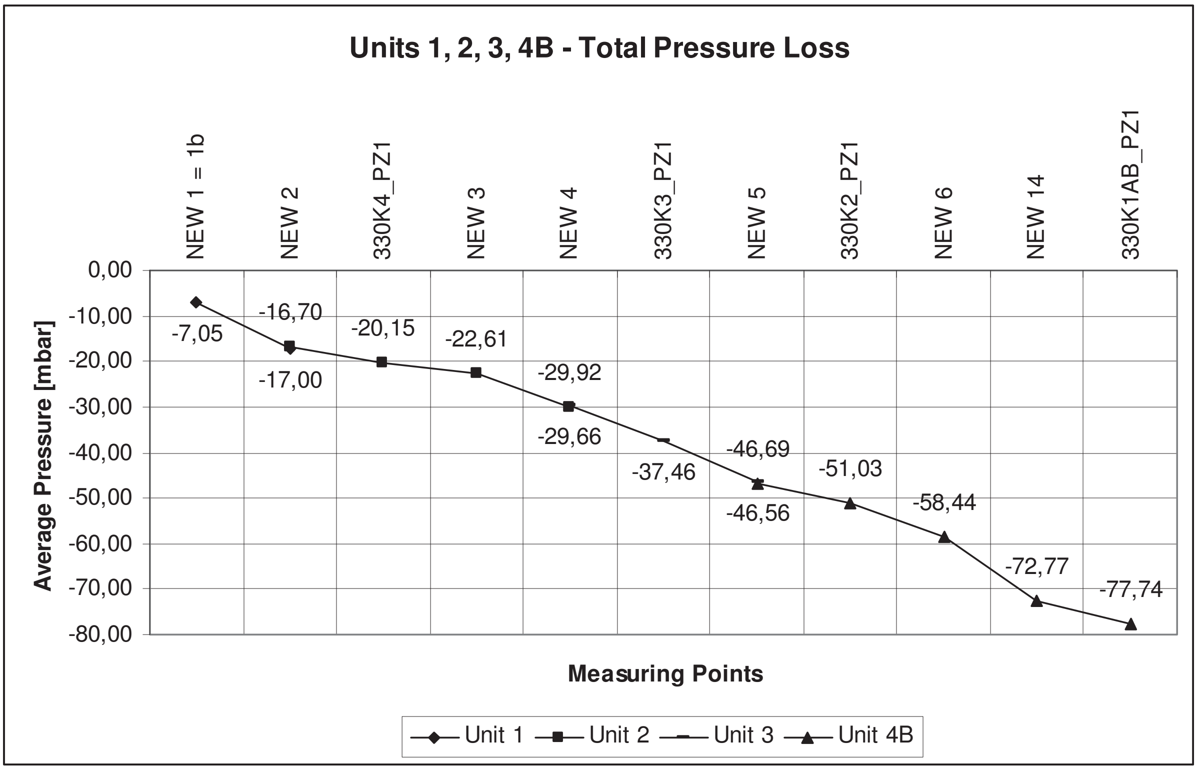

Figure 15: Units 1, 2, 3, 4B – Total Pressure Loss

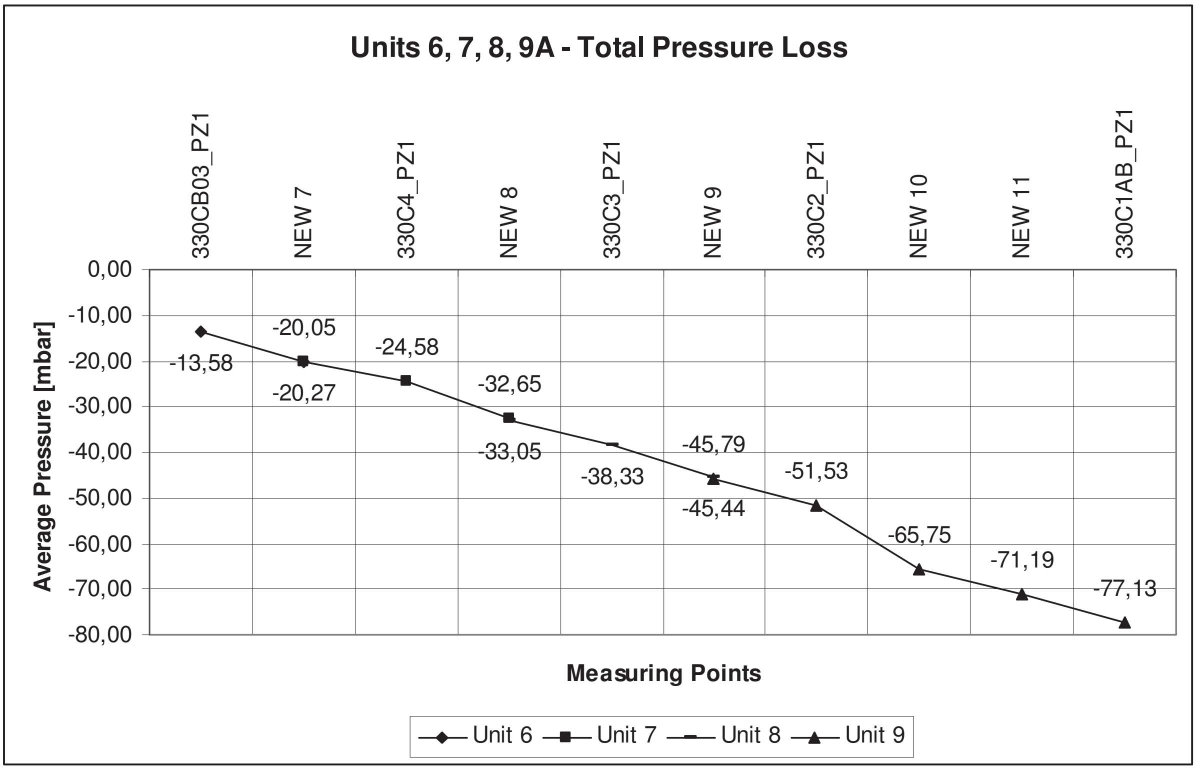

Figure 16: Units 6, 7, 8, 9A – Total Pressure Loss

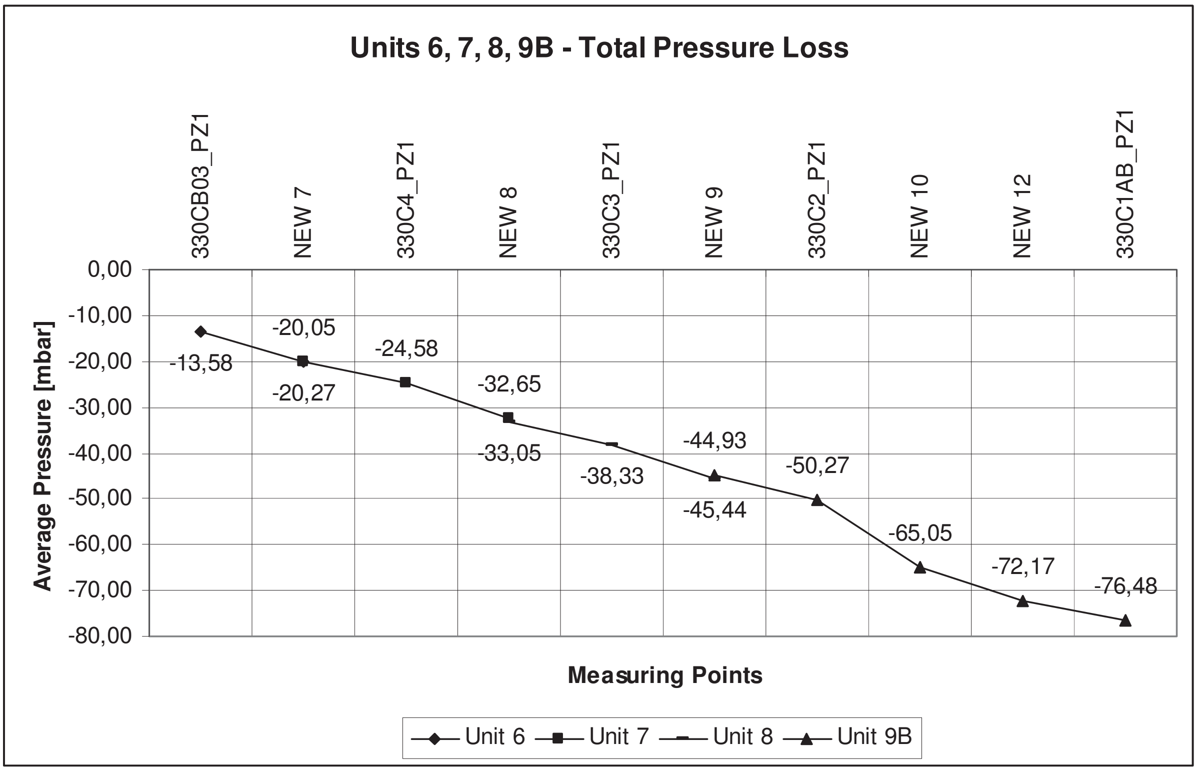

Figure 17: Units 6, 7, 8, 9B – Total Pressure Loss

7.2.4 Pressure Loss of Single Units

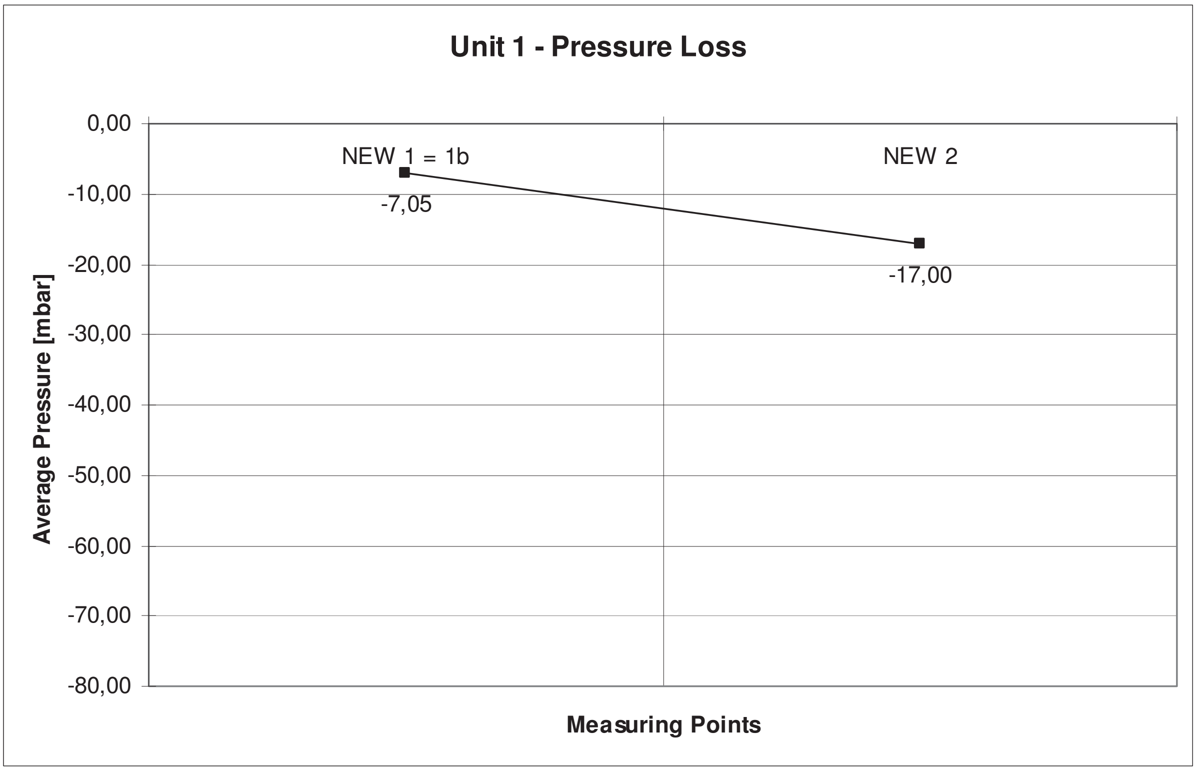

Figure 18: Unit 1 – Pressure Loss

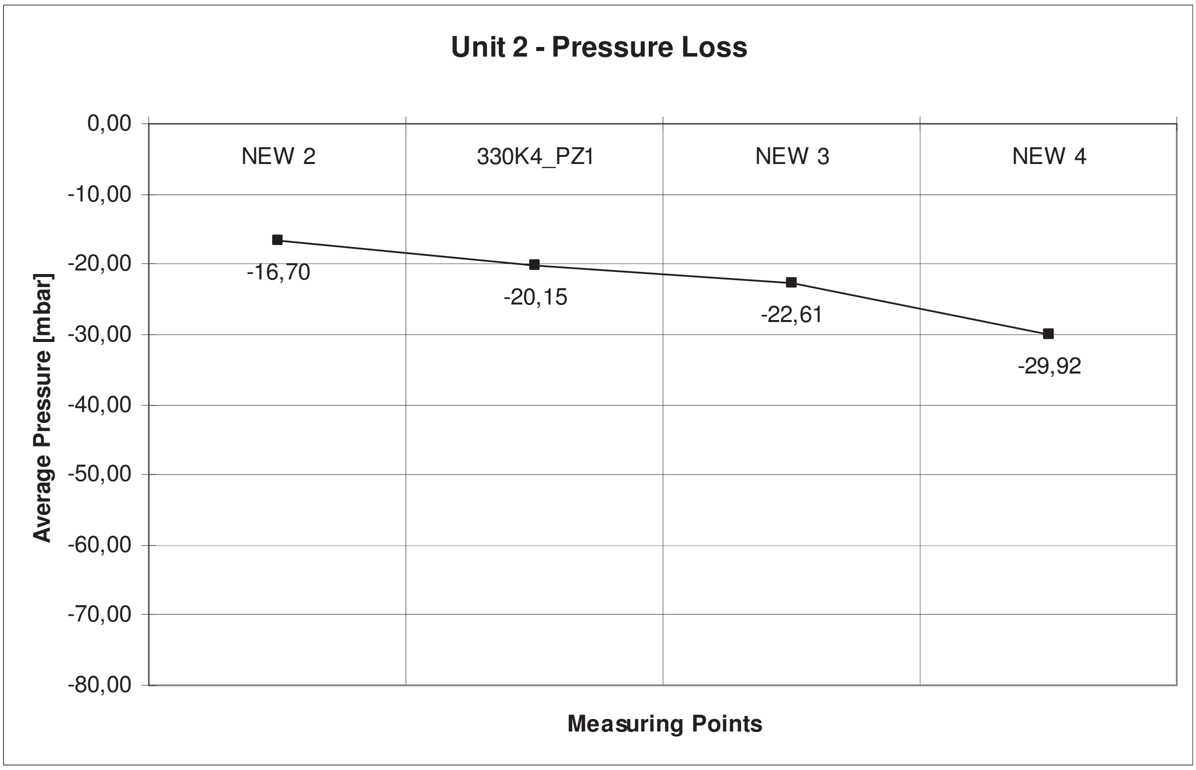

Figure 19: Unit 2 – Pressure Loss

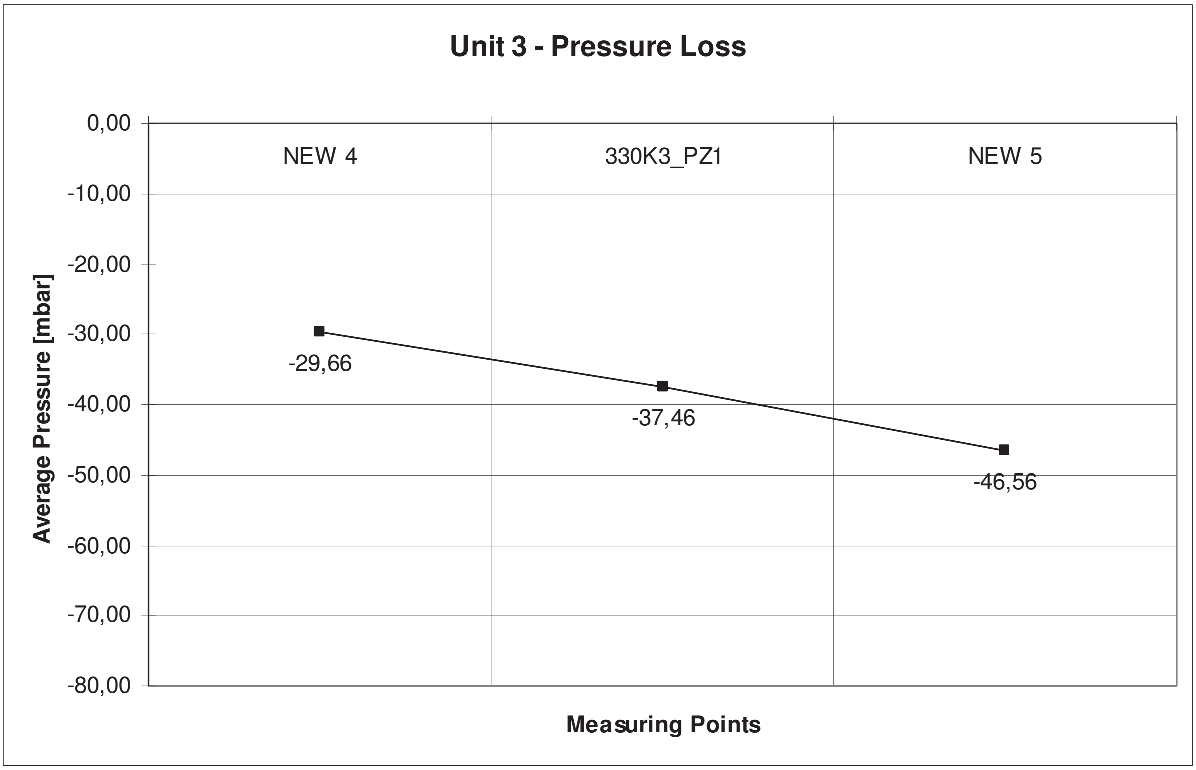

Figure 20: Unit 3 – Pressure Loss

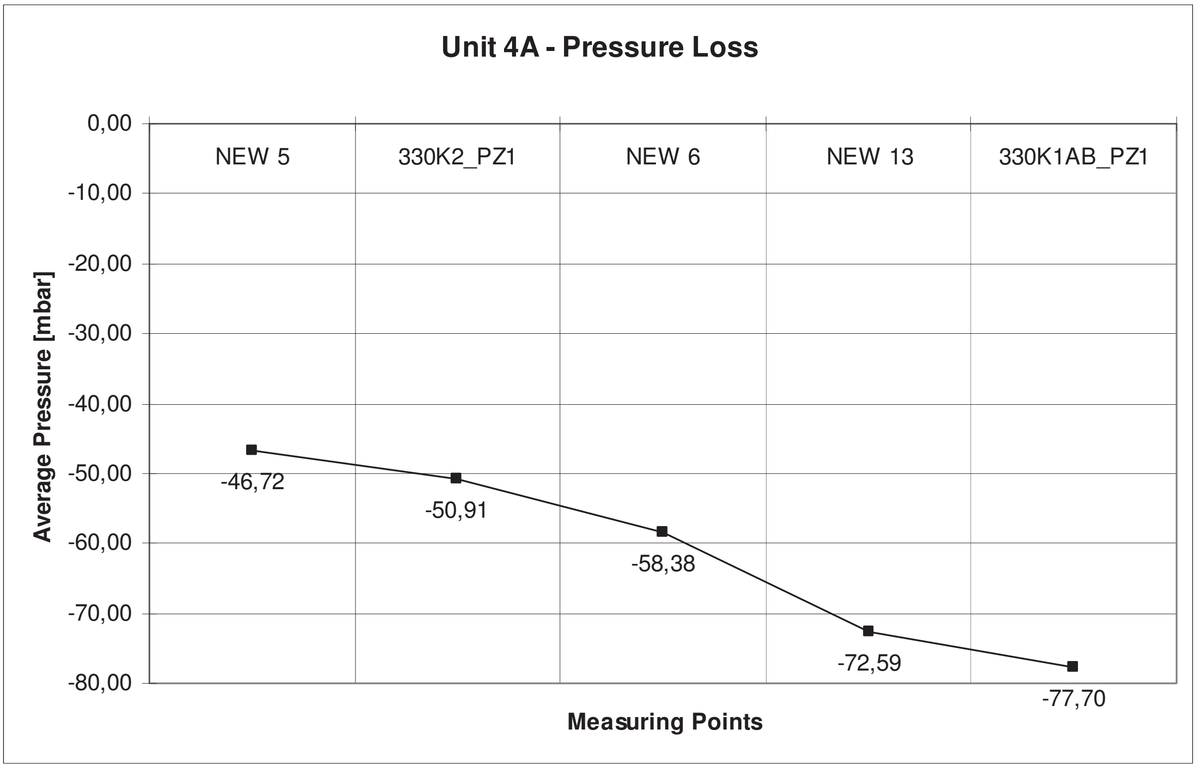

Figure 21: Unit 4A – Pressure Loss

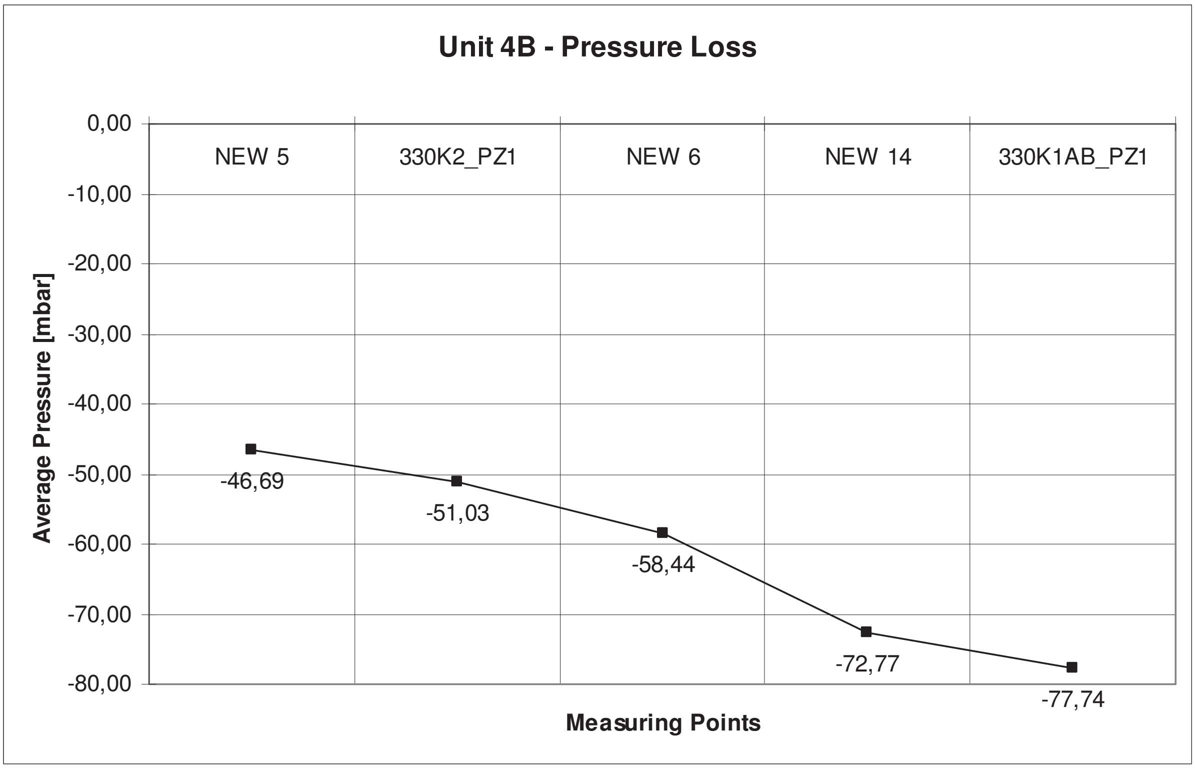

Figure 22: Unit 4B – Pressure Loss

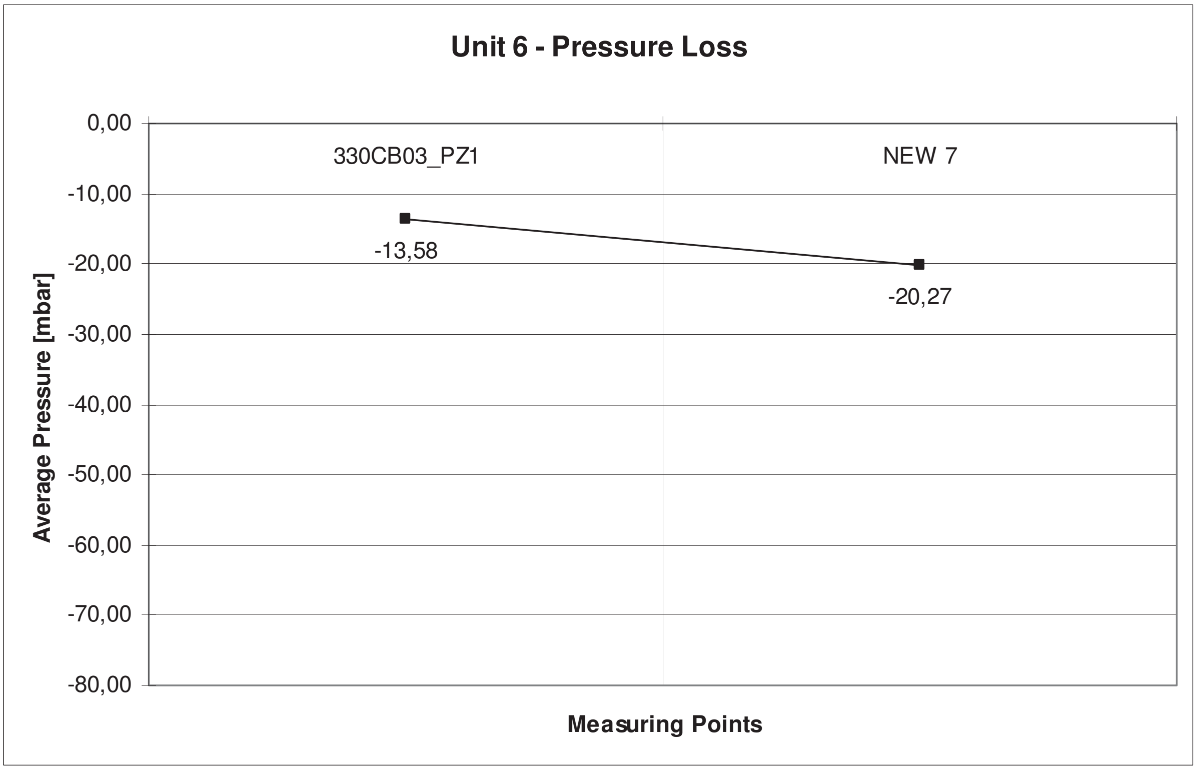

Figure 23: Unit 6 – Pressure Loss

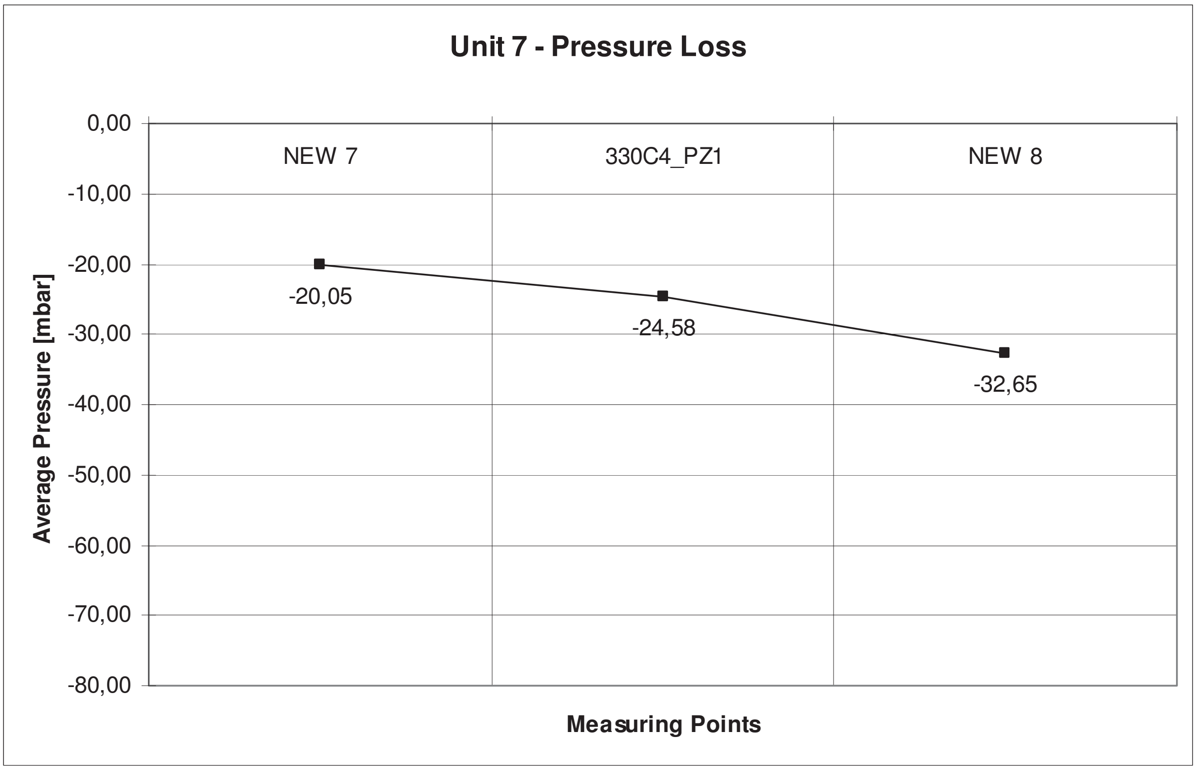

Figure 24: Unit 7 – Pressure Loss

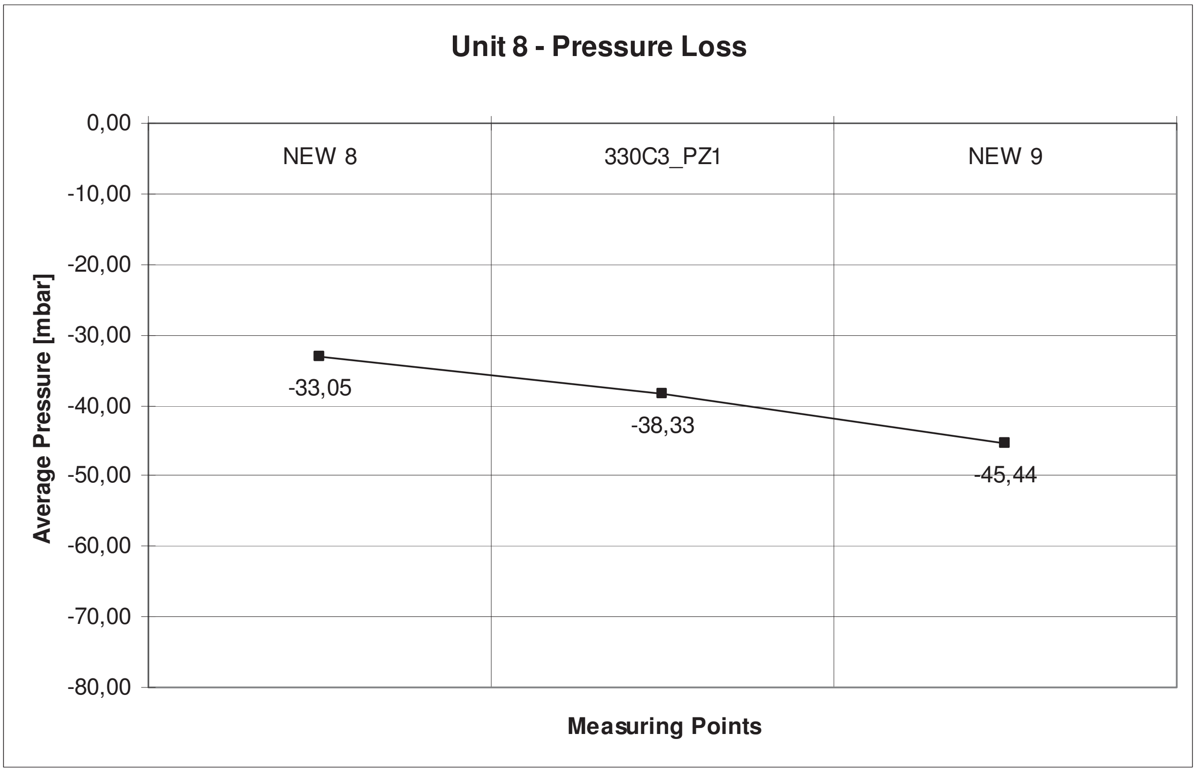

Figure 25: Unit 8 – Pressure Loss

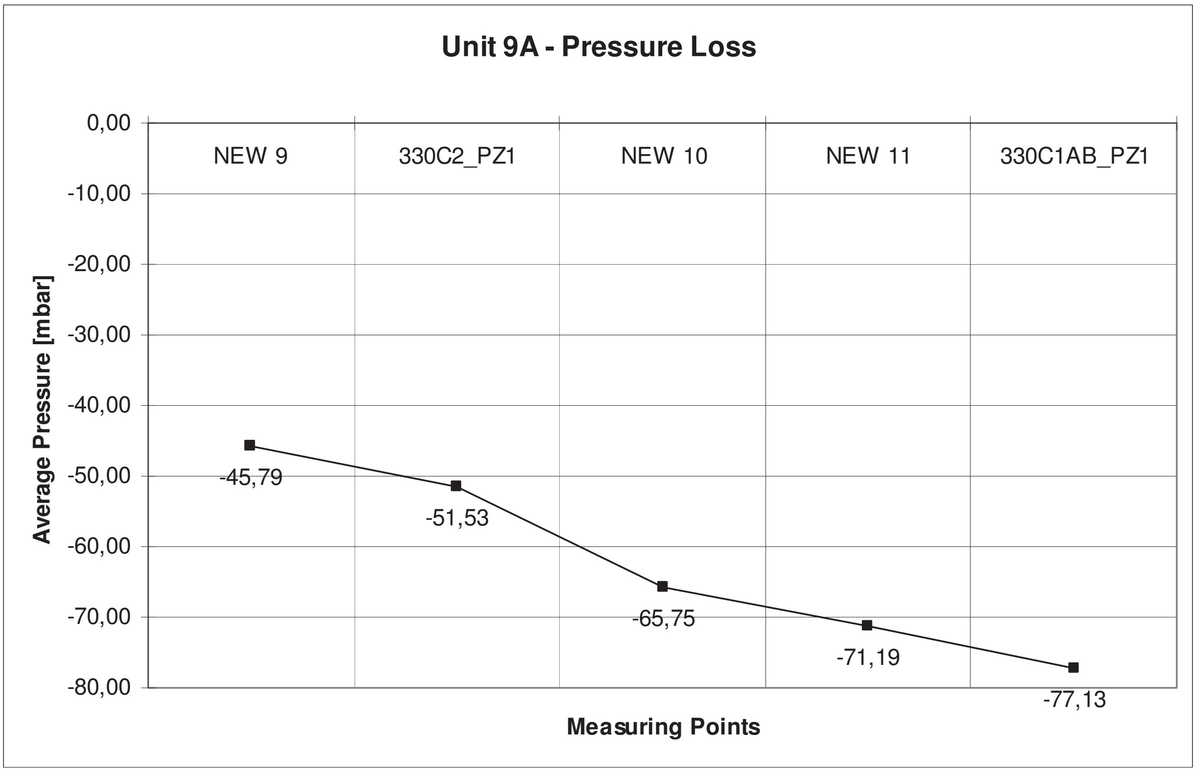

Figure 26: Unit 9A – Pressure Loss

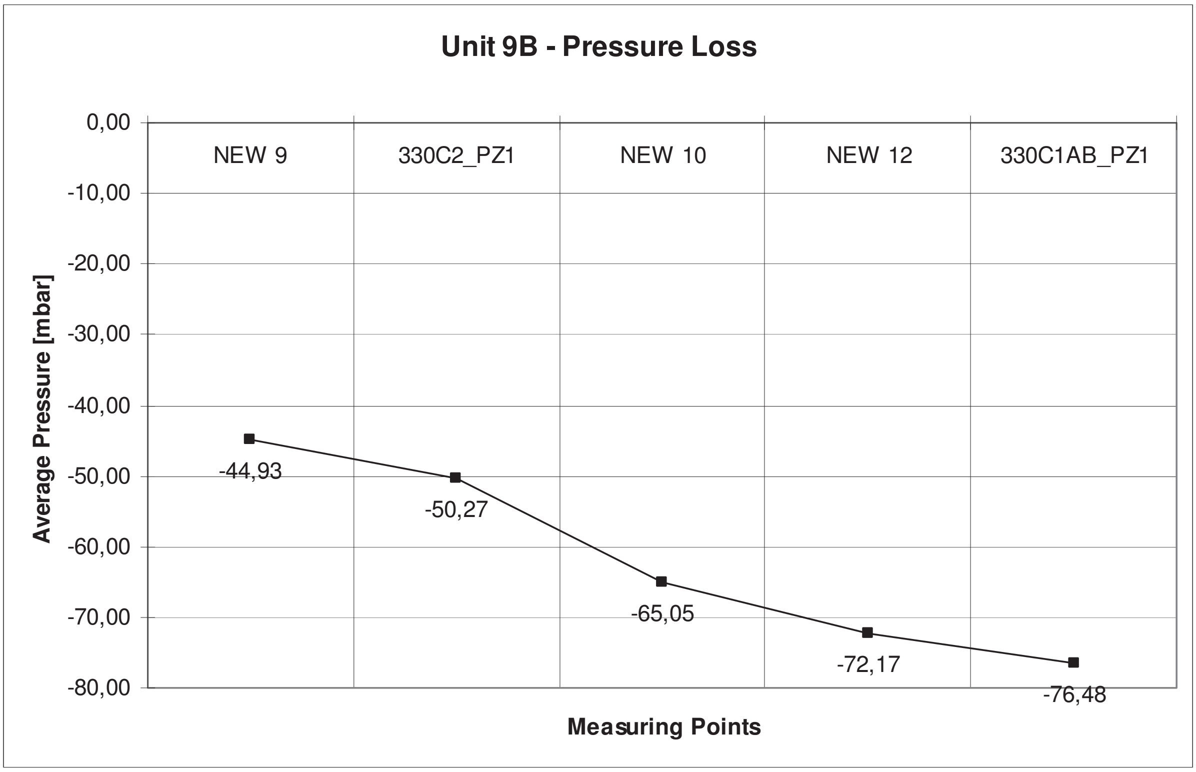

Figure 27: Unit 9B - Pressure Loss

7.2.5 Delta Pressure

For getting an overview about pressure loss between the different measuring points, a well-defined compilation is displayed in Table 24 and Table 25.

Table 24: Units 1, 2, 3, 4A, 4B – Delta Pressure

Units 1, 2, 3, 4A		
Measuring Point 1	**Measuring Point 2**	**Delta Pressure [mbar]**
NEW 1 = 1b	NEW 2	-9,96
NEW 2	330K4_PZ1	-3,46
330K4_PZ1	NEW 3	-2,46
NEW 3	NEW 4	-7,31
NEW 4	330K3_PZ1	-7,79
330K3_PZ1	NEW 5	-9,10
NEW 5	330K2_PZ1	-4,19
330K2_PZ1	NEW 6	-7,47
NEW 6	NEW 13	-14,21
NEW 13	330K1AB_PZ1	-5,11

Units 1, 2, 3, 4B		
Measuring Point 1	**Measuring Point 2**	**Delta Pressure [mbar]**
NEW 1 = 1b	NEW 2	-9,96
NEW 2	330K4_PZ1	-3,46
330K4_PZ1	NEW 3	-2,46
NEW 3	NEW 4	-7,31
NEW 4	330K3_PZ1	-7,79
330K3_PZ1	NEW 5	-9,10
NEW 5	330K2_PZ1	-4,34
330K2_PZ1	NEW 6	-7,41
NEW 6	NEW 14	-14,33
NEW 14	330K1AB_PZ1	-4,98

Table 25: Units 6, 7, 8, 9A, 9B – Delta Pressure

Units 6, 7, 8, 9A		
Measuring Point 1	**Measuring Point 2**	**Delta Pressure [mbar]**
330CB03_PZ1	NEW 7	-6,69
NEW 7	330C4_PZ1	-4,53
330C4_PZ1	NEW 8	-8,07
NEW 8	330C3_PZ1	-5,28
330C3_PZ1	NEW 9	-7,12
NEW 9	330C2_PZ1	-5,74
330C2_PZ1	NEW 10	-14,22
NEW 10	NEW 11	-5,45
NEW 11	330C1AB_PZ1	-5,93

Units 6, 7, 8, 9B		
Measuring Point 1	**Measuring Point 2**	**Delta Pressure [mbar]**
330CB03_PZ1	NEW 7	-6,69
NEW 7	330C4_PZ1	-4,53
330C4_PZ1	NEW 8	-8,07
NEW 8	330C3_PZ1	-5,28
330C3_PZ1	NEW 9	-7,12
NEW 9	330C2_PZ1	-5,74
330C2_PZ1	NEW 10	-14,22
NEW 10	NEW 12	-5,45
NEW 12	330C1AB_PZ1	-5,93

The graphical interpretation in Figure 28 till Figure 31 reveals that especially the transition zone between NEW 1 and NEW 2, as well as between NEW 6 and NEW 13 alternatively NEW 14 shows a high pressure loss. The crossover of the gas flow from riser duct RK1 into the twin cyclones with two gas flows consumes a lot of lifting force.

On the one hand the transition zone between 330C2_PZ1 and NEW 10 goes up in value of delta pressure; that fact is explained primarily by the superior length of the riser duct RC1. And on the other hand the complete raw meal input NEW M11 attracts attention to pressure loss in area NEW 5 to NEW 6.

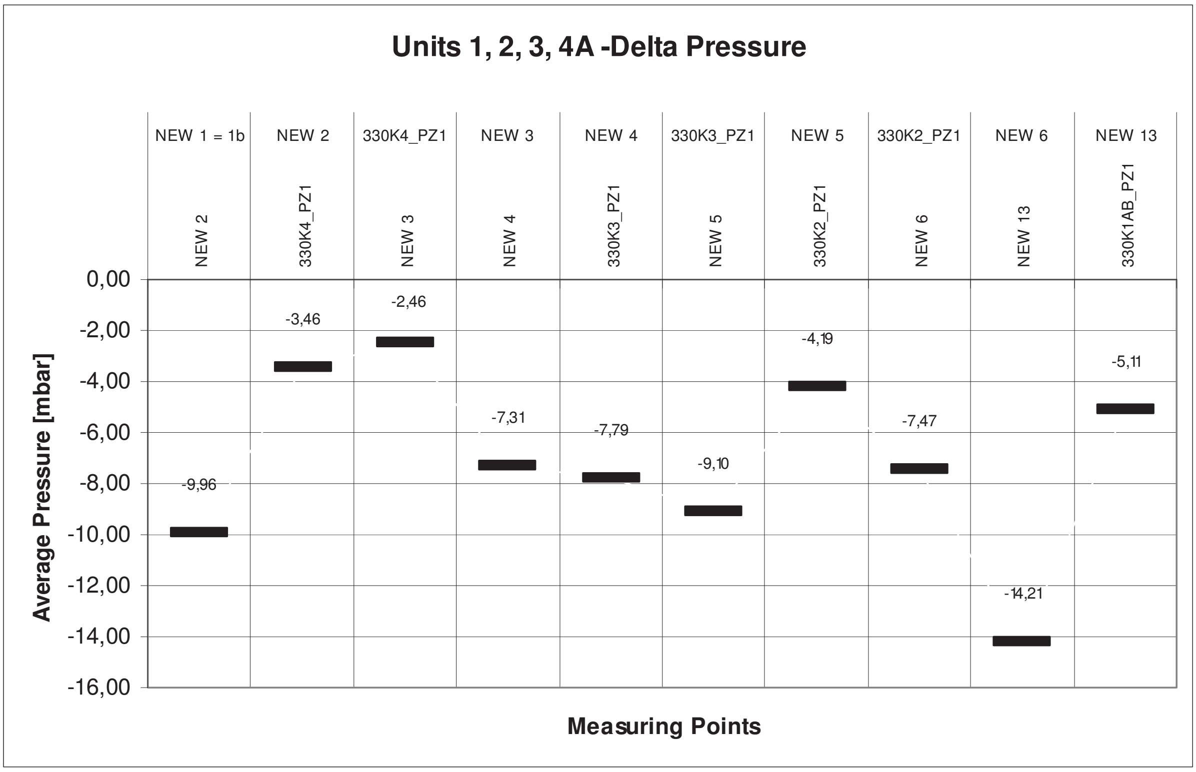

Figure 28: Units 1, 2, 3, 4A – Delta Pressure

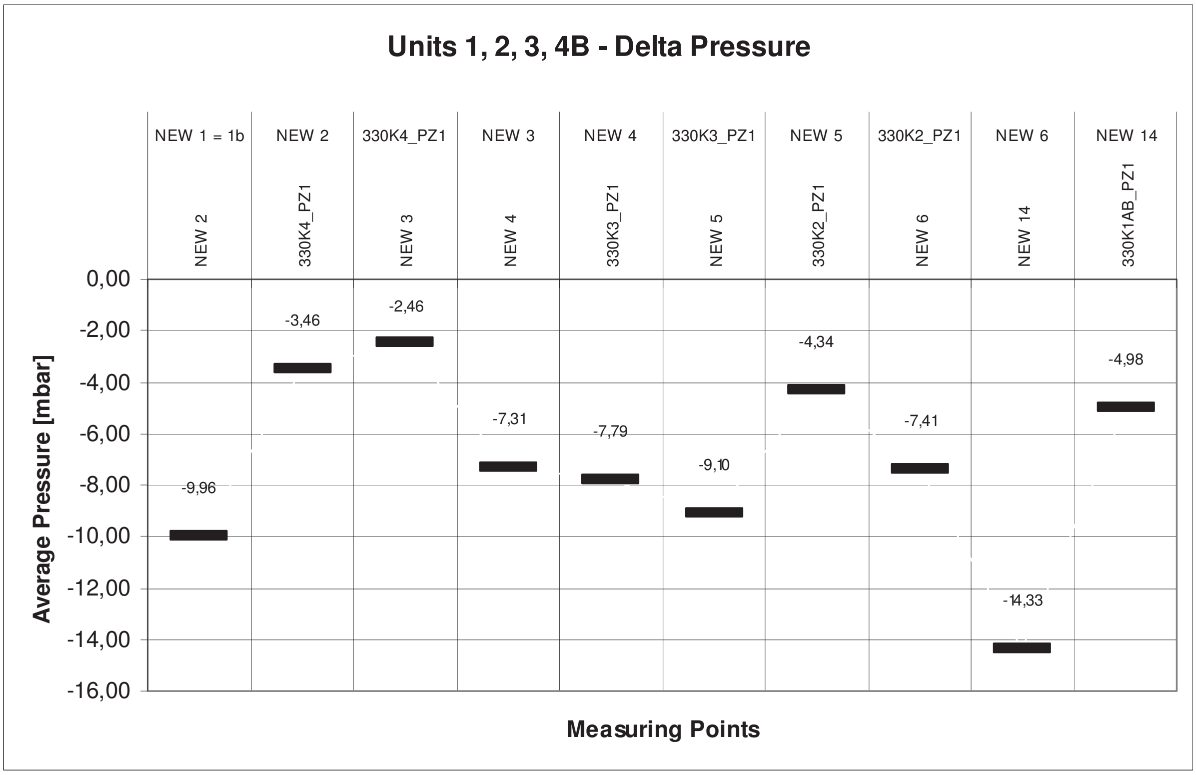

Figure 29: Units 1, 2, 3, 4B – Delta Pressure

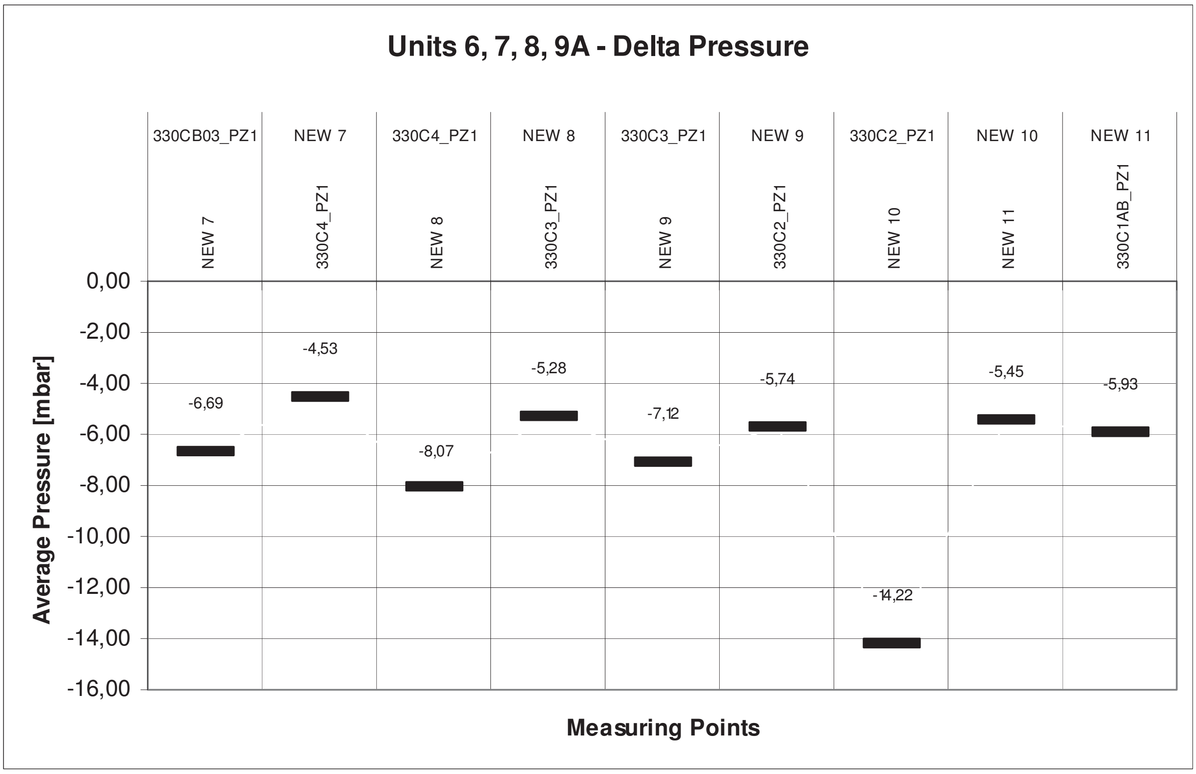

Figure 30: Units 6, 7, 8, 9A – Delta Pressure

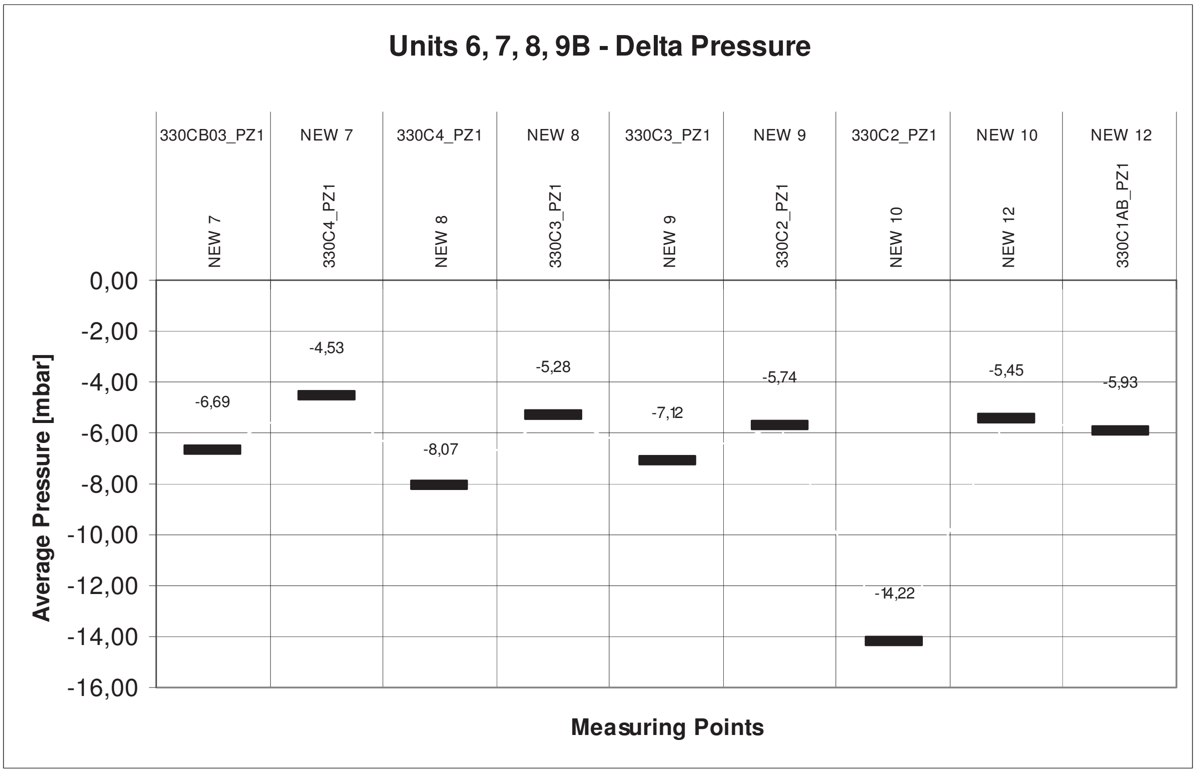

Figure 31: Units 6, 7, 8, 9B – Delta Pressure

7.3 Temperature

Measured data of hand-held measurement and results of modified measuring values from MIS – Management Information System are to be found for the kiln string in Table 26 and Table 27, those for the calciner string in Table 28 and Table 29.

The graphical demonstration reveals Figure 32 till Figure 37. Figure 38 up to Figure 49 show the temperature for the single units. Continuous heating of raw meal is demonstrated in Figure 50 up to Figure 53.

High irregularity in the chart features measuring point 330K4_TZ1 which depends on the position of the existing thermocouple. Reason for this low value is that the meal pipe MPC2 enters the riser duct RK3 directly shortly above the installed thermocouple which is encountered with cold raw meal.

Measuring point NEW 7 shows the effects on combustion of coal in the calciner by slightly raised temperature values. The drop of temperature in riser ducts is higher than in cyclones and can be confirmed by according consideration of measuring points, 330C3_TZ1 to NEW 8 for instance with high decrease of temperature. Heat transfer in riser ducts between gas flow and meal flow is effective.

7.3.1 Results of Kiln String

Table 26: Kin String – Temperature (1)

Kiln String							
Date	**Unit**	**Signals**	**Measuring Point**	**Data Logger**	**Channel**	**Average Temperature [°C]**	**Standard Deviation**
04.08.2006	1	6	NEW 1 = 1b	25	3	811,86	3,17
			NEW 2	25	1	753,84	6,01
			NEW M1	28	1	833,40	1,23
			NEW M3	28	2	708,08	1,86
			330KI01_TZ1			1031,87	9,71
			330CB01_TZ1			811,86	3,98
07.08.2006	2	8	NEW 2	25	1	758,95	6,00
			NEW 3	28	1	665,33	1,78
			NEW 4	28	3	648,61	1,00
			NEW M4	25	4	644,60	0,66
			NEW M5	25	3	551,06	26,37
			330K4_TZ1			617,52	3,79
01.08.2006	3	7	NEW 4	28	1	649,40	0,91
			NEW 5	25	3	415,87	3,29
			NEW M6	25	1	470,23	0,67
			NEW M7	28	3	364,63	0,62
			NEW M8	28	4	364,55	0,74
			330K3_TZ1			564,23	3,97

Table 27: Kiln String – Temperature (2)

Kiln String							
Date	Unit	Signals	Measuring Point	Data Logger	Channel	Average Temperature [°C]	Standard Deviation
01.08.2006	4A	7 (+1)	NEW 5	25	1	416,30	5,74
			NEW 6	28	1	241,40	1,28
			NEW 13	28	3	235,79	0,85
			NEW M9	25	3	247,93	1,60
			NEW M10	25	4	235,19	0,83
			NEW M11			74,21	0,21
			330K1AB_TZ1			211,54	1,86
			330K2_TZ1			245,99	2,03
01.08.2006	4B	7 (+1)	NEW 5	25	1	413,69	4,99
			NEW 6	28	1	241,62	1,38
			NEW 14	28	3	240,73	0,74
			NEW M9	25	3	247,28	1,31
			NEW M10	25	4	235,22	0,77
			NEW M11			74,21	0,21
			330K1AB_TZ1			216,06	1,78
			330K2_TZ1			238,04	1,77

7.3.2 Results of Calciner String

Table 28: Calciner String – Temperature (1)

Calciner String							
Date	Unit	Signals	Measuring Point	Data Logger	Channel	Average Temperature [°C]	Standard Deviation
04.08.2006	6	6	NEW 7	25	1	904,49	4,79
			NEW M1	28	2	890,74	6,50
			NEW M2	28	1	835,54	0,91
			NEW 15	25	3	888,97	6,78
			NEW 16	28	3	946,77	1,37
			330CB03_TZ1			882,03	7,58
03.08.2006	7	6	NEW 7	28	1	912,13	5,74
			NEW 8	25	1	742,28	2,60
			NEW M3	28	3	716,49	2,41
			NEW M4	25	3	651,52	0,53
			330C4_TZ1			794,67	5,75
03.08.2006	8	6	NEW 8	25	1	735,73	3,35
			NEW 9	28	1	517,26	4,98
			NEW M5	25	3	566,42	1,01
			NEW M6	28	3	471,00	0,88
			330C3_TZ1			533,23	1,77

Table 29: Calciner String – Temperature (2)

Calciner String							
Date	**Unit**	**Signals**	**Measuring Point**	**Data Logger**	**Channel**	**Average Temperature [°C]**	**Standard Deviation**
02.08.2006	9A	8 (+2)	NEW 9	28	1	518,11	3,43
			NEW 10	25	1	373,66	0,87
			NEW 11	25	3	365,61	0,73
			NEW M9	28	3	237,81	0,66
			NEW M10	28	4	247,60	0,92
			330C1AB_TZ1			321,52	0,75
			330C2_TZ1			347,49	1,66
02.08.2006	9A	8 (+2)	NEW 9	28	1	514,50	4,75
			NEW 10	25	1	374,14	1,06
			NEW 11	25	3	366,52	0,72
			NEW M7	28	4	365,79	0,70
			NEW M8	28	3	359,34	0,70
			330C1AB_TZ1			316,10	2,56
			330C2_TZ1			353,72	2,02
02.08.2006	9B	8 (+2)	NEW 9	28	1	512,38	4,41
			NEW 10	25	1	374,05	1,25
			NEW 12	25	3	366,78	0,90
			NEW M7	28	4	365,70	0,85
			NEW M8	28	3	357,94	1,32
			330C1AB_TZ1			318,33	2,11
			330C2_TZ1			358,91	0,40
02.08.2006	9B	8 (+2)	NEW 9	28	1	508,06	4,47
			NEW 10	25	1	372,92	0,77
			NEW 12	25	3	366,04	0,66
			NEW M9	28	3	236,31	0,61
			NEW M10	28	4	238,28	0,92
			330C1AB_TZ1			318,91	2,08
			330C2_TZ1			355,48	0,52

7.3.3 Total Temperature

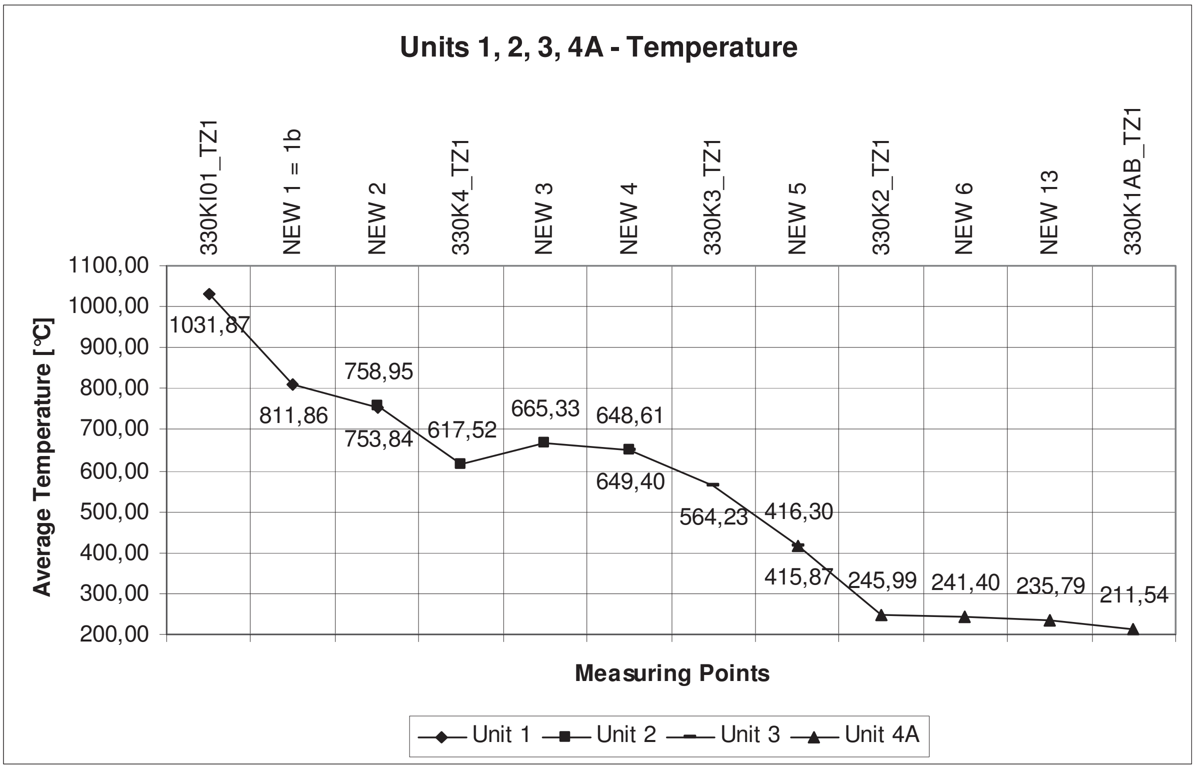

Figure 32: Units 1, 2, 3, 4A - Temperature

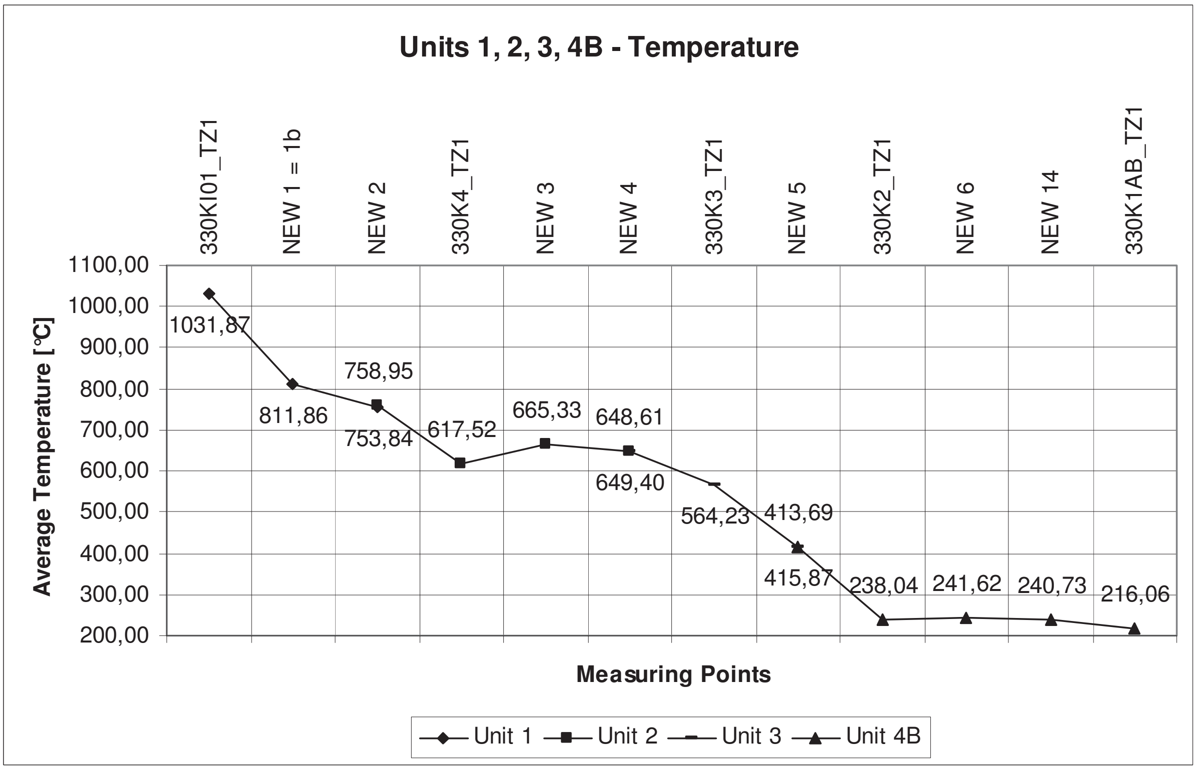

Figure 33: Units 1, 2, 3, 4B - Temperature

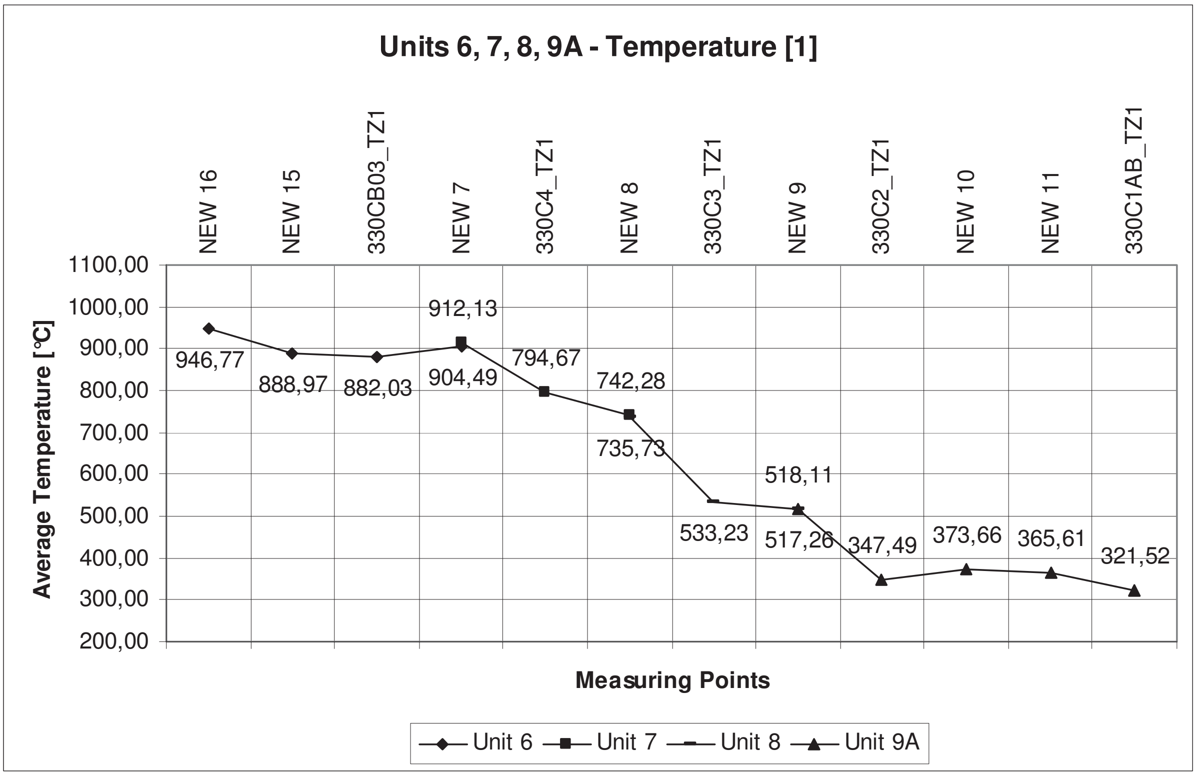

Figure 34: Units 6, 7, 8, 9A – Temperature [1]

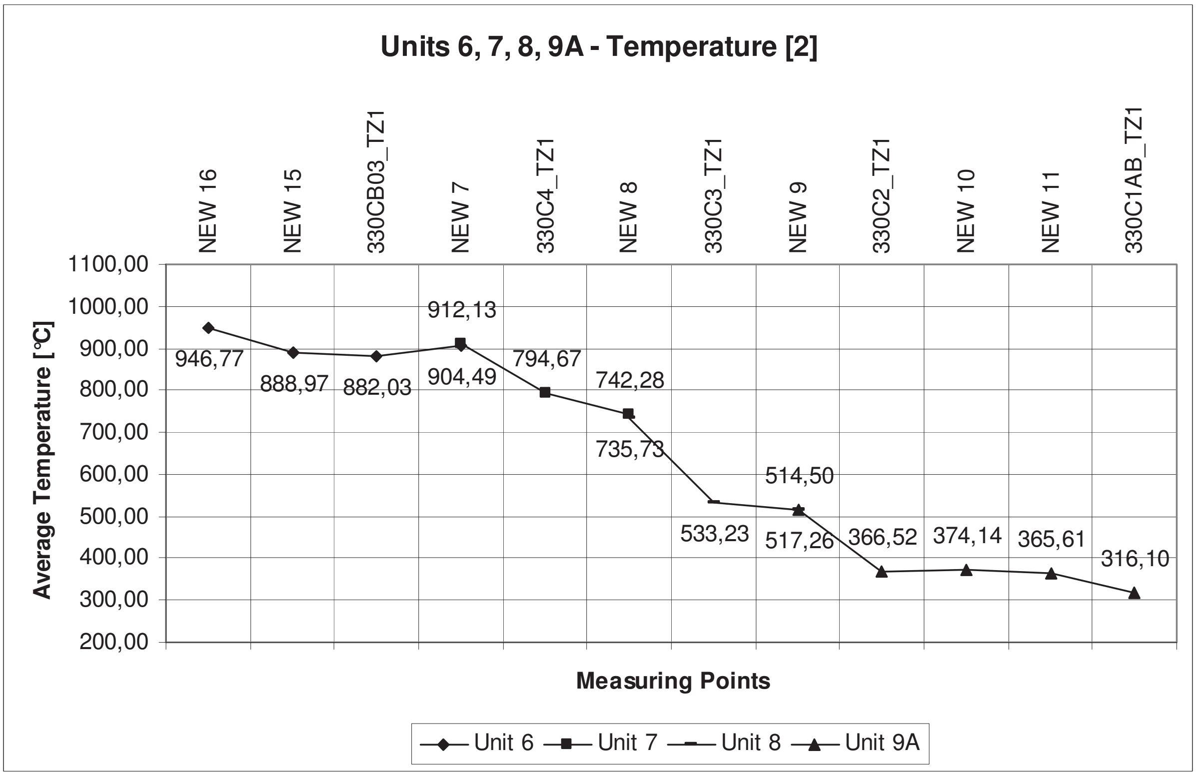

Figure 35: Units 6, 7, 8, 9A – Temperature [2]

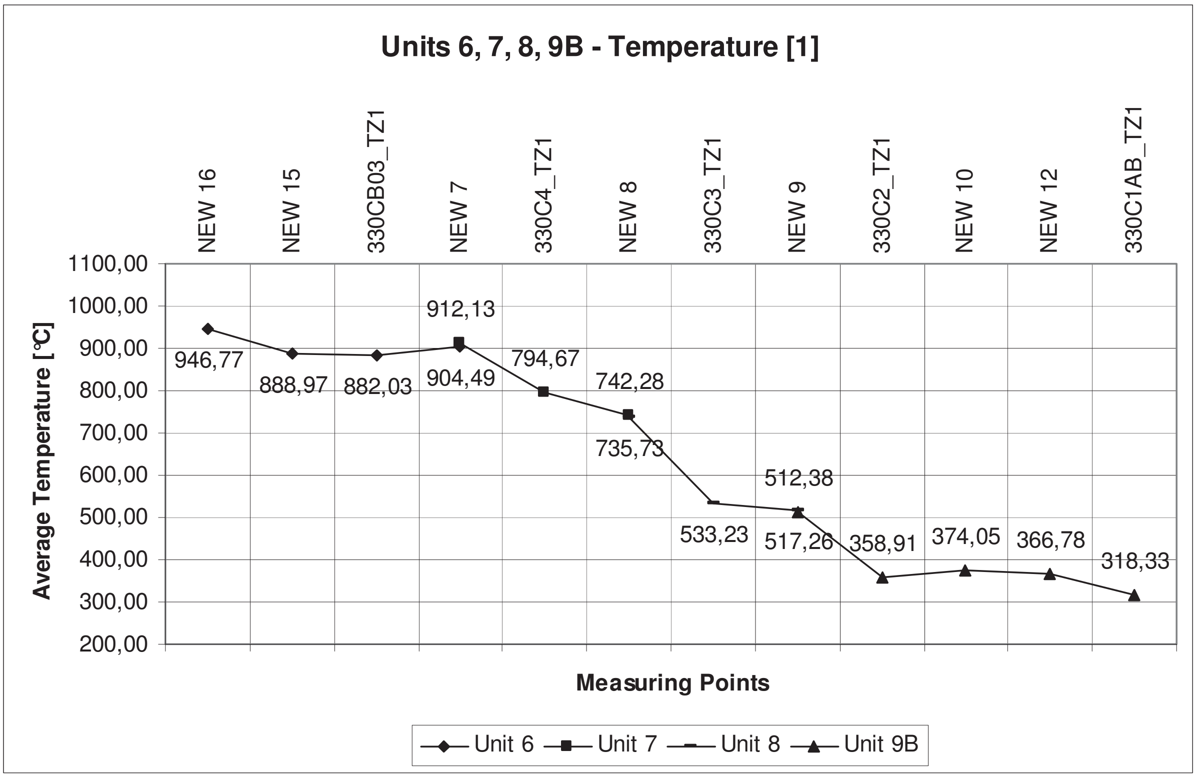

Figure 36: Units 6, 7, 8, 9B – Temperature [1]

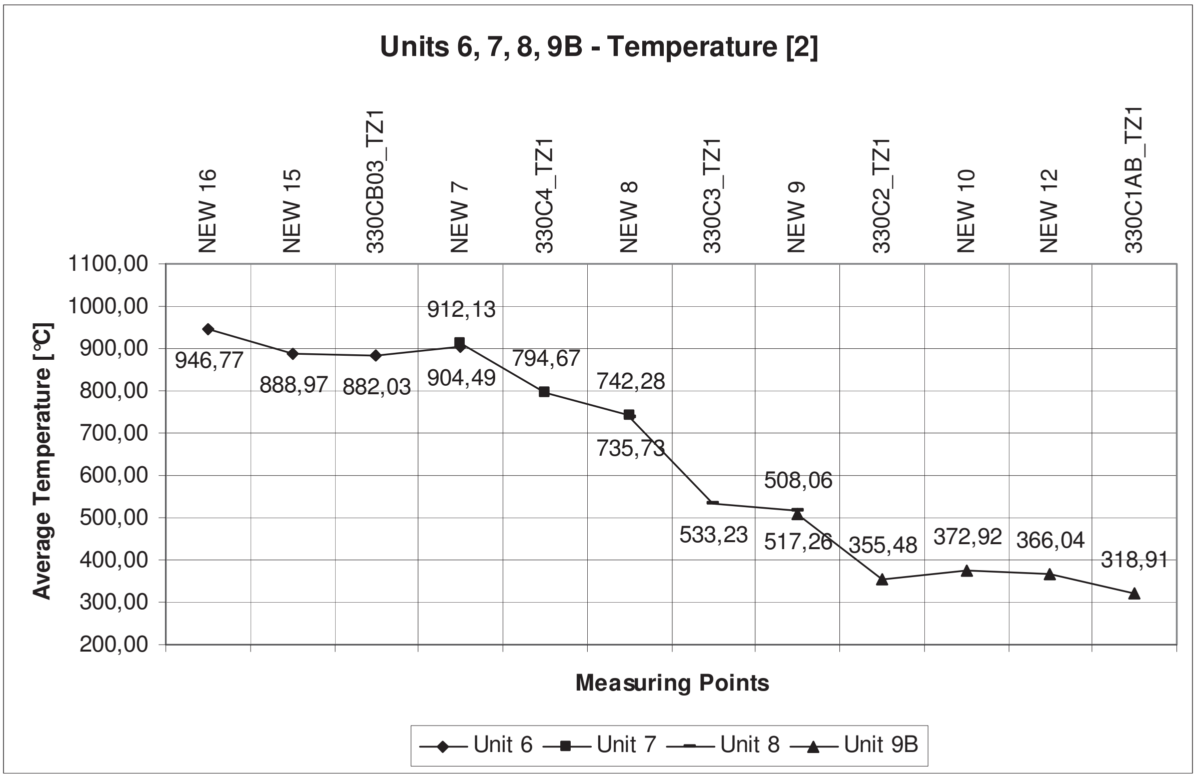

Figure 37: Units 6, 7, 8, 9B – Temperature [2]

7.3.4 Temperature of Single Units

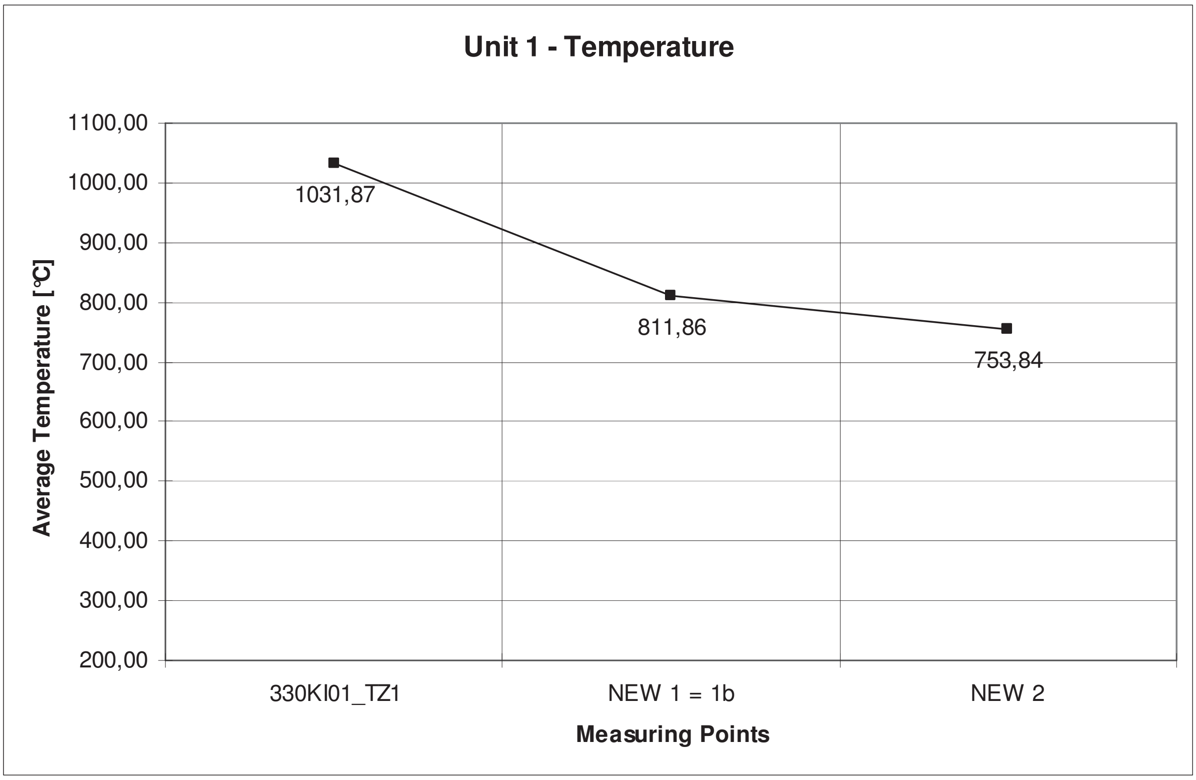

Figure 38: Unit 1 - Temperature

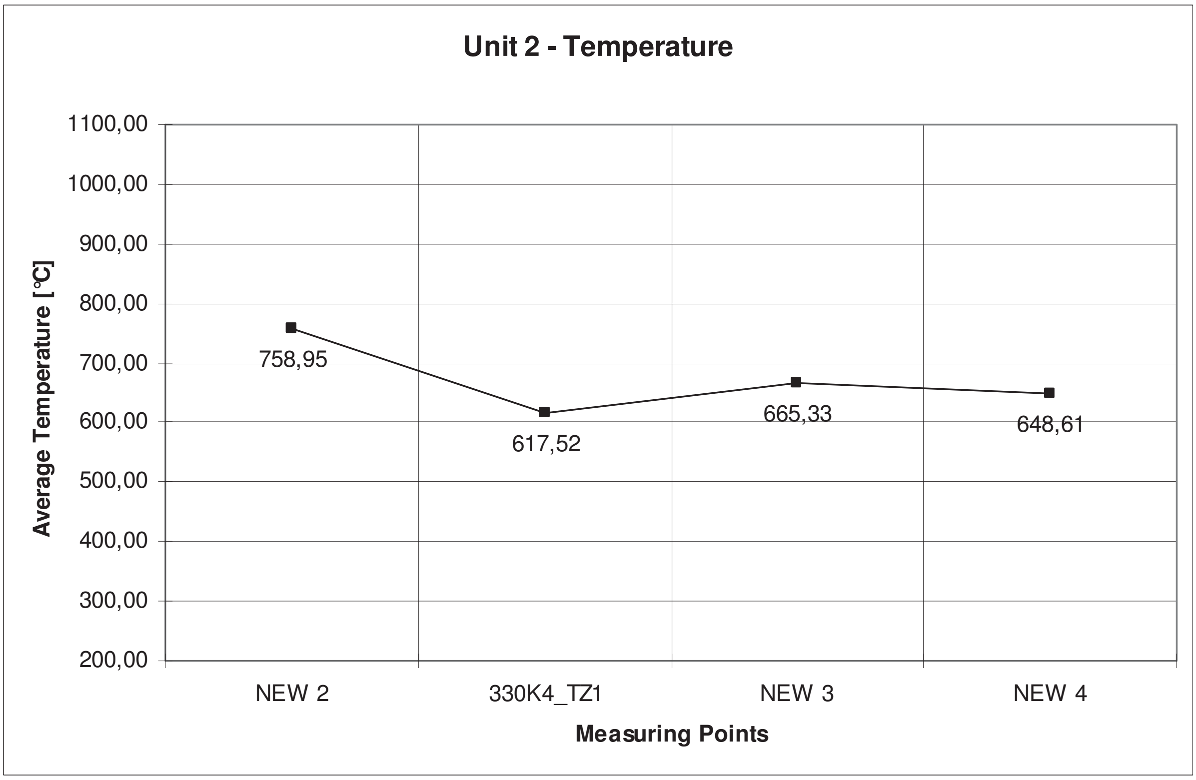

Figure 39: Unit 2 - Temperature

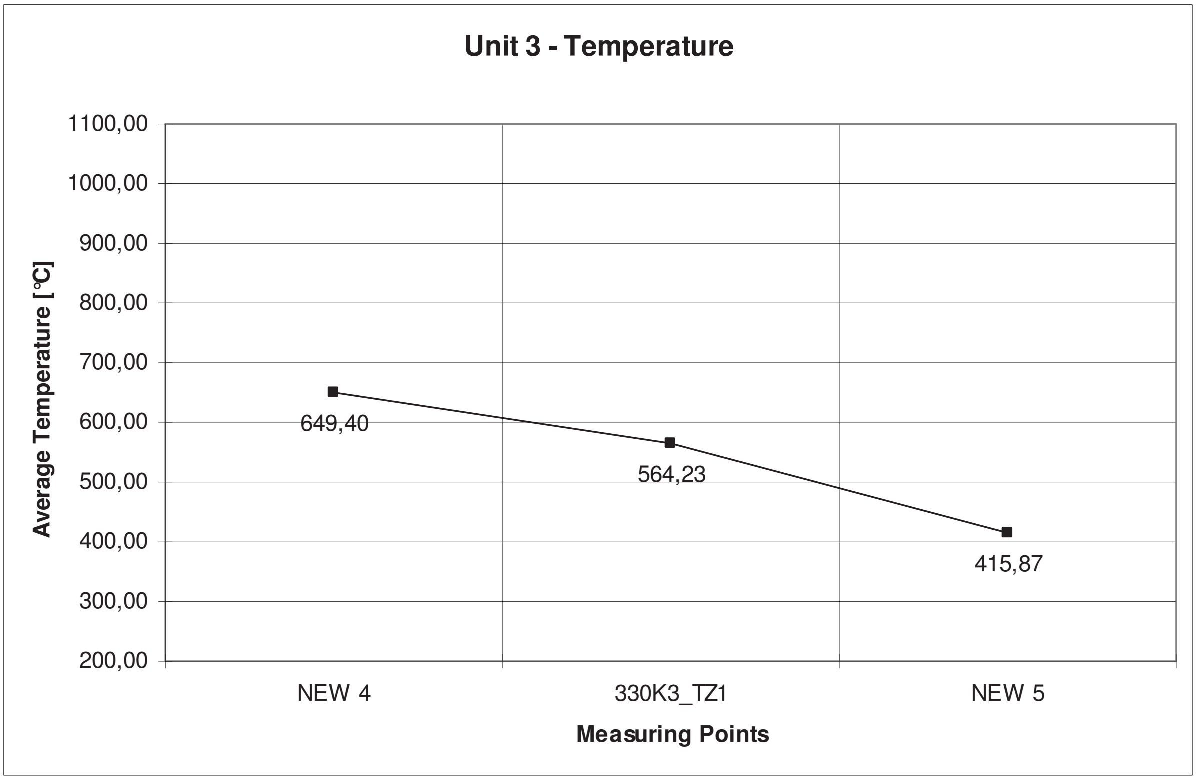

Figure 40: Unit 3 - Temperature

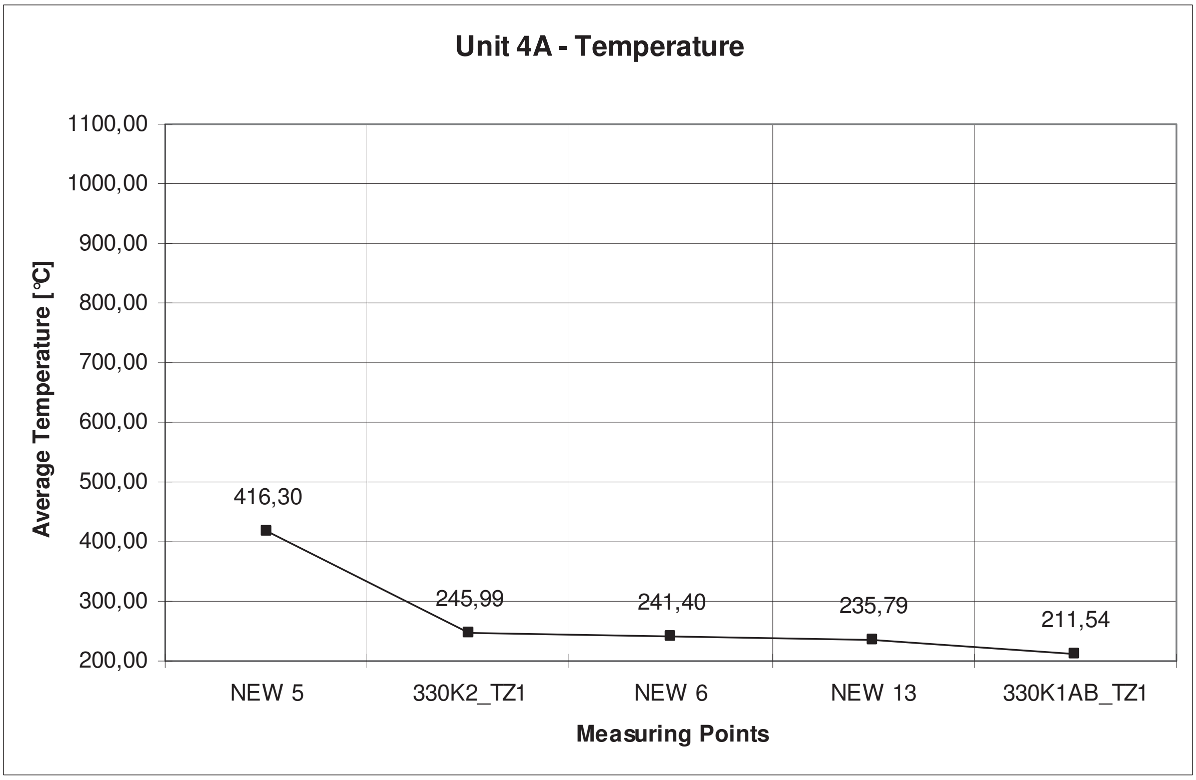

Figure 41: Unit 4A - Temperature

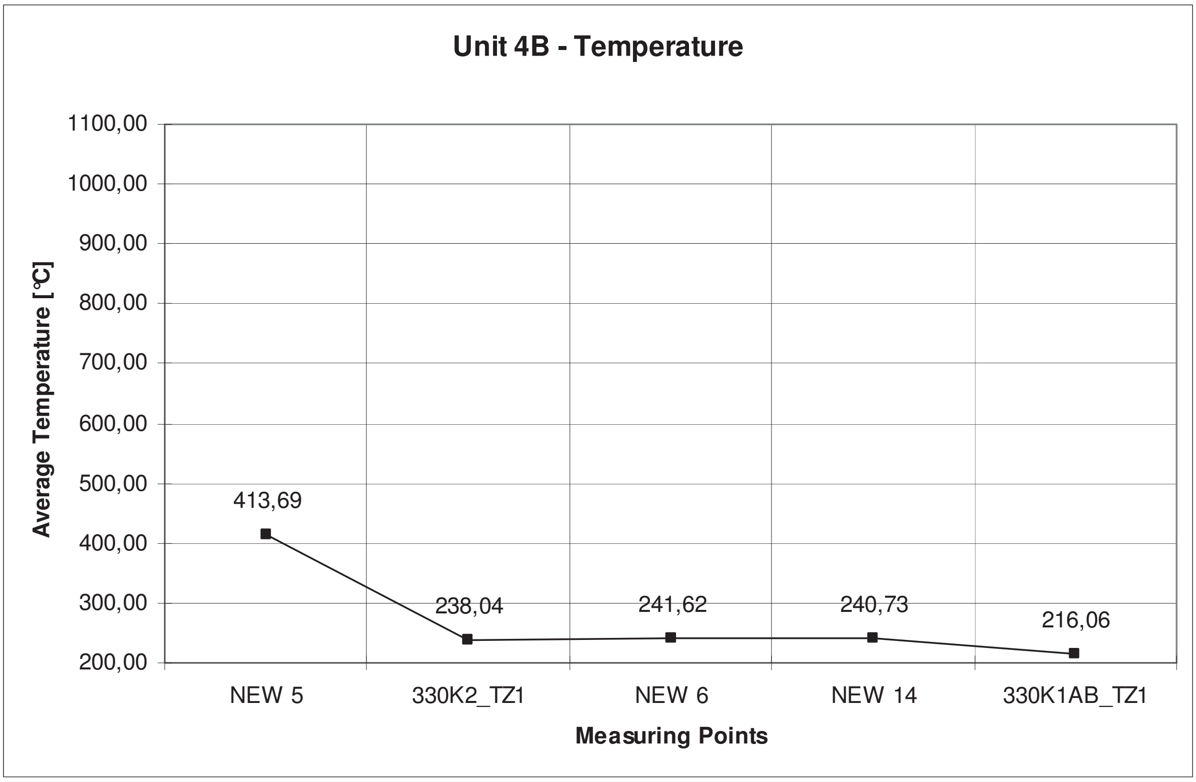

Figure 42: Unit 4B - Temperature

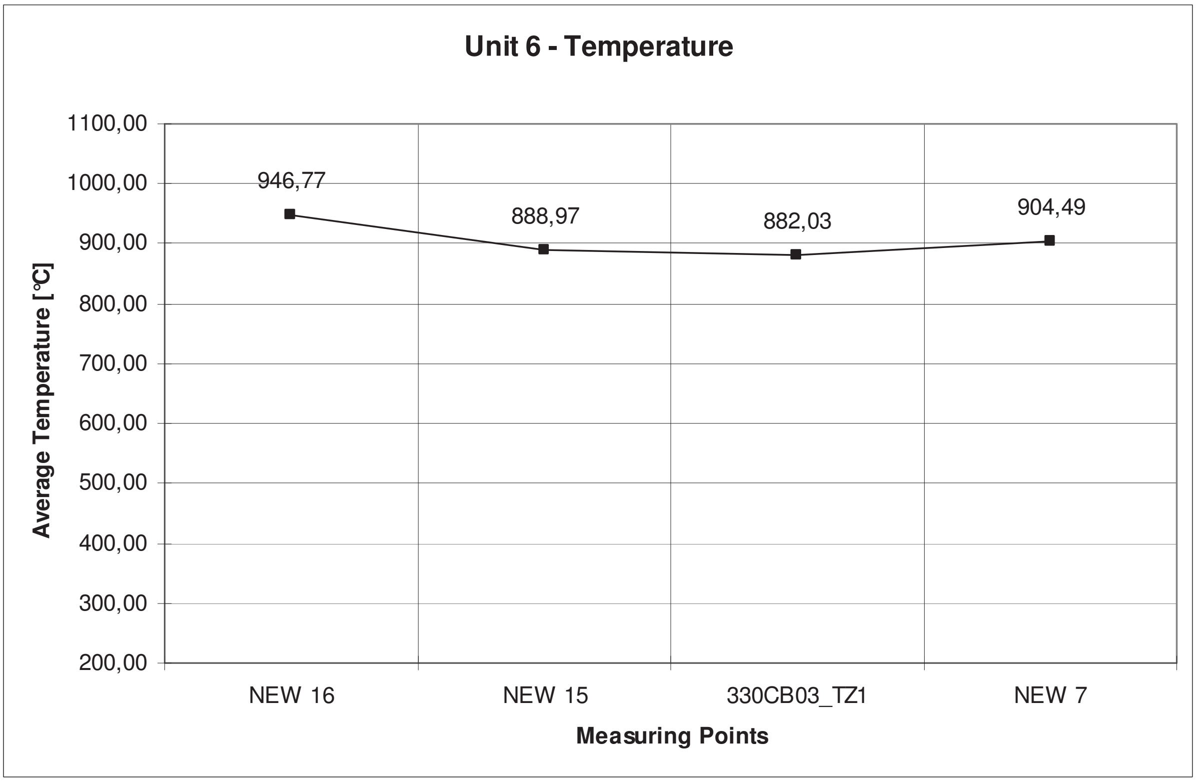

Figure 43: Unit 6 - Temperature

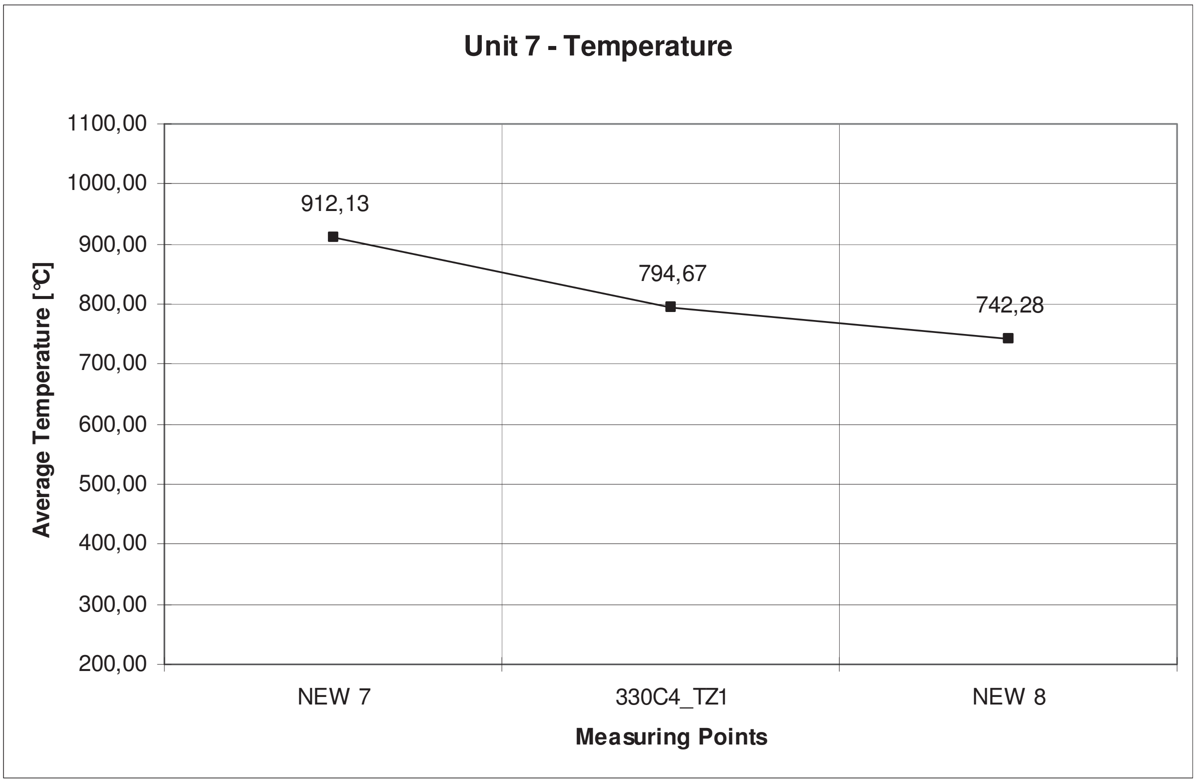

Figure 44: Unit 7 - Temperature

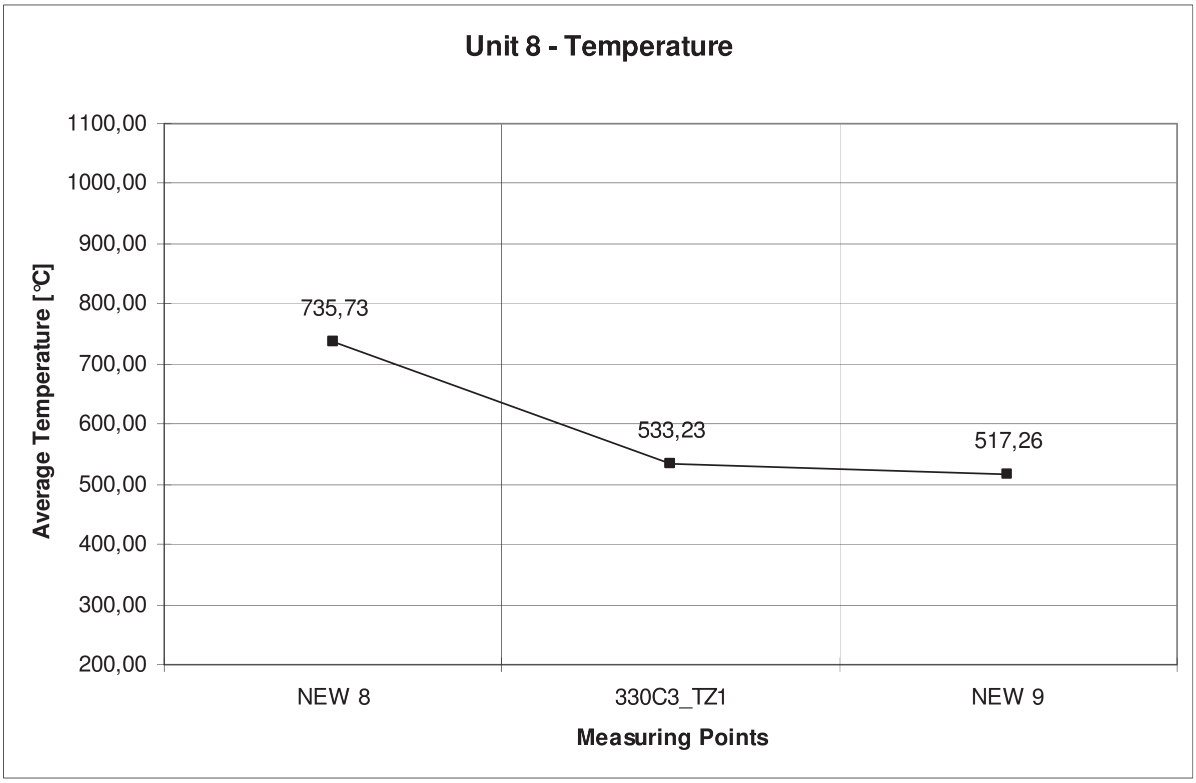

Figure 45: Unit 8 - Temperature

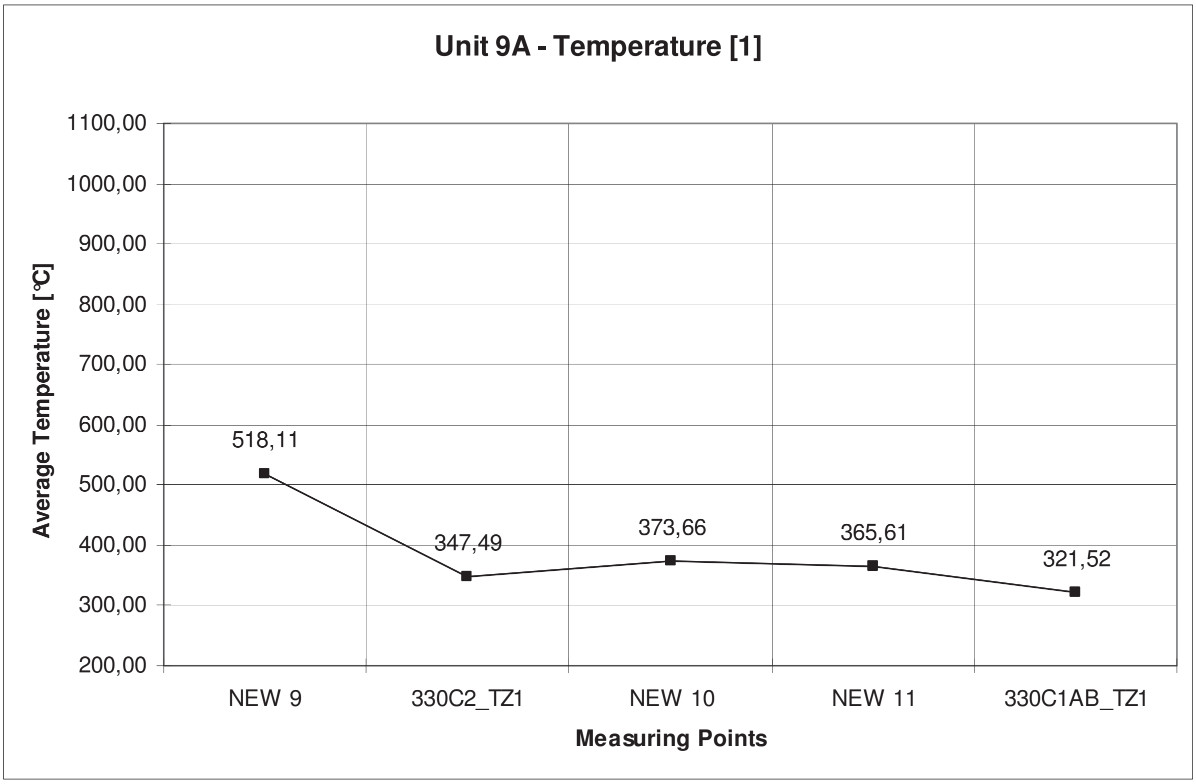

Figure 46: Unit 9A – Temperature [1]

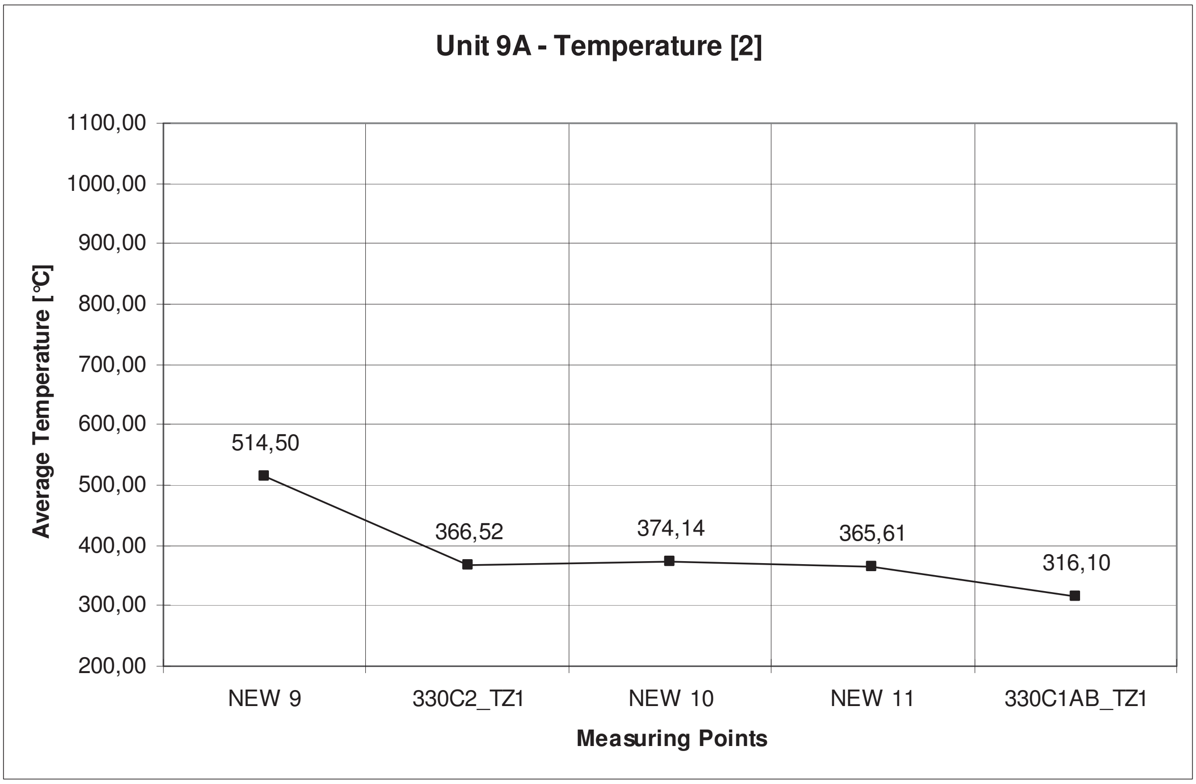

Figure 47: Unit 9A – Temperature [2]

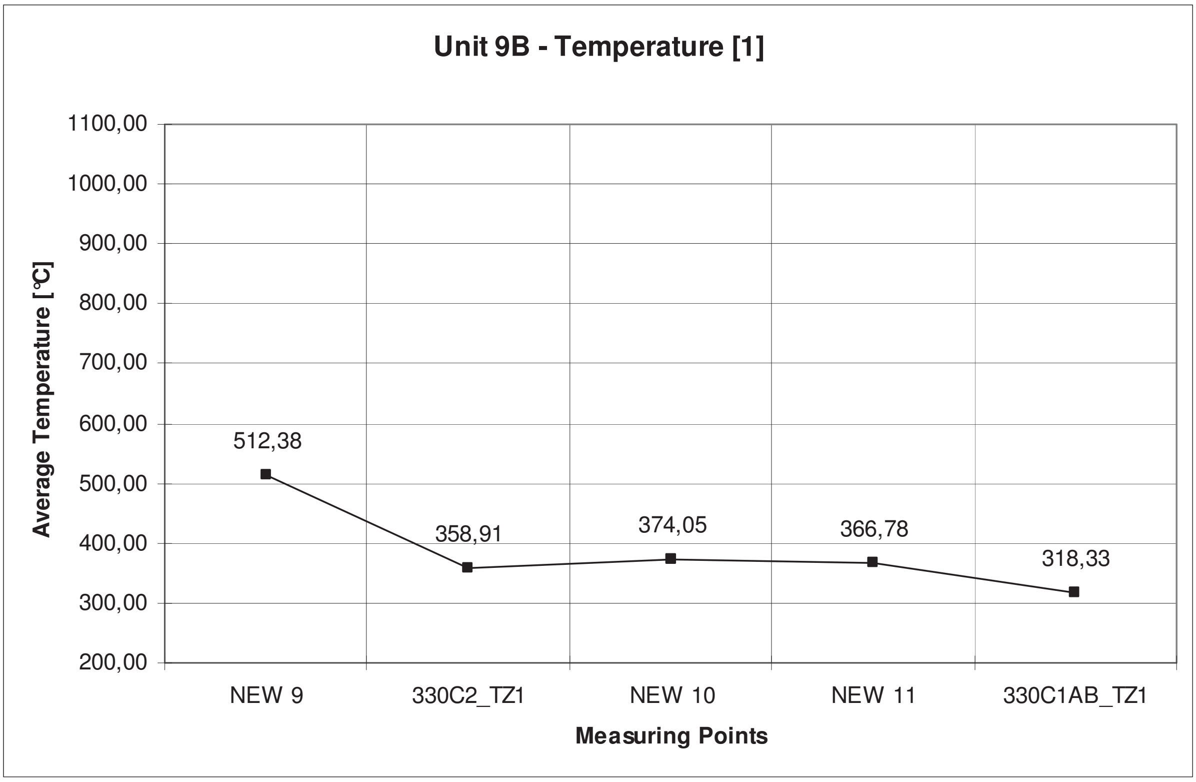

Figure 48: Unit 9B – Temperature [1]

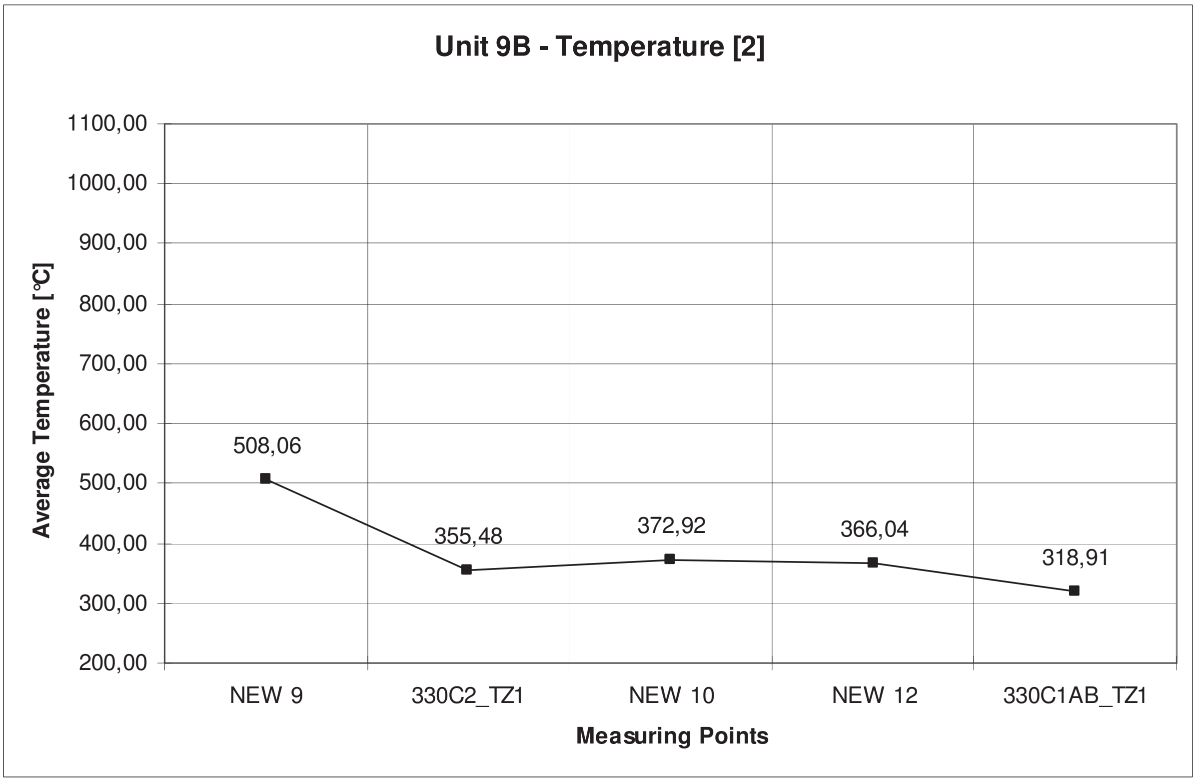

Figure 49: Unit 9B – Temperature [2]

7.4 Meal Temperature

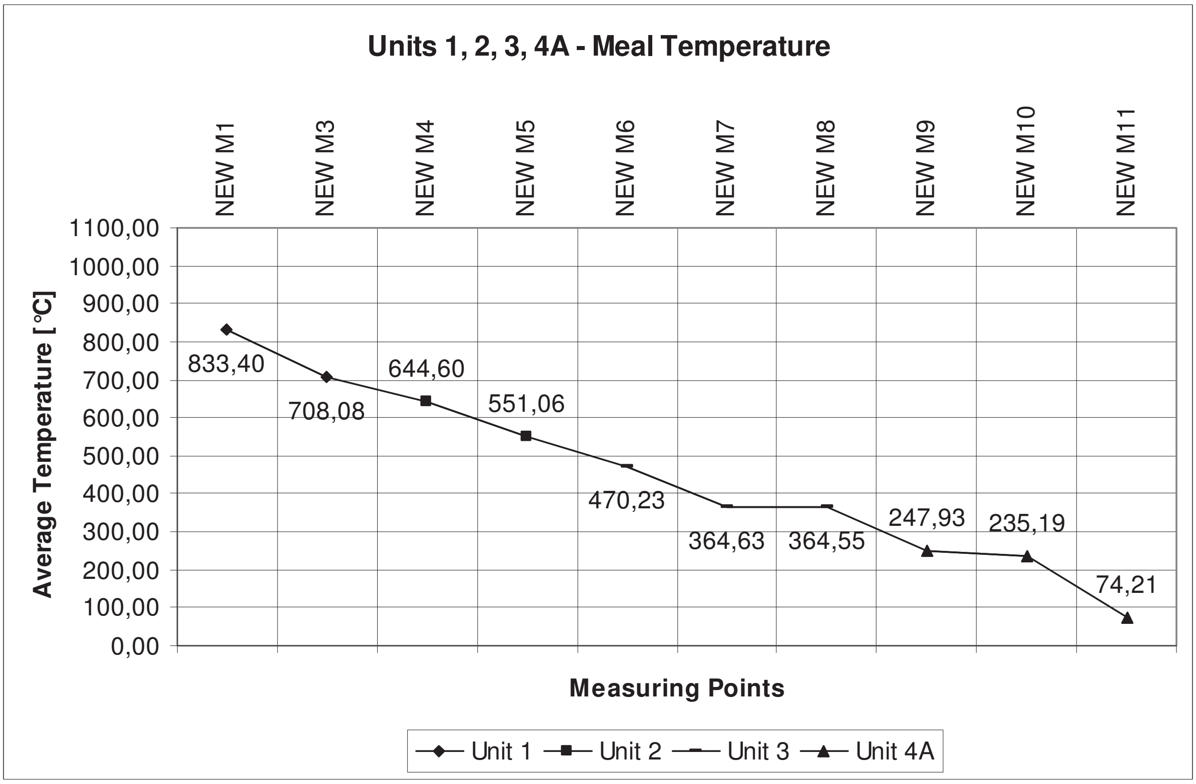

Figure 50: Units 1, 2, 3, 4A – Meal Temperature

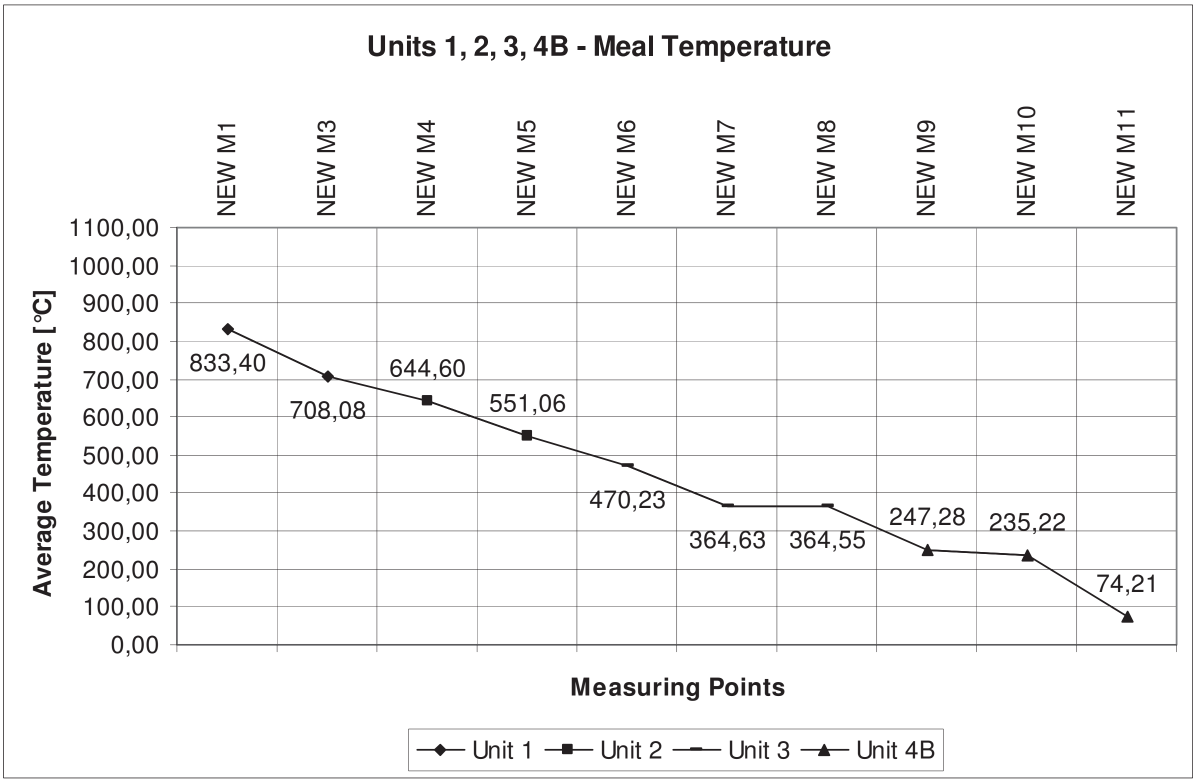

Figure 51: Units 1, 2, 3, 4B – Meal Temperature

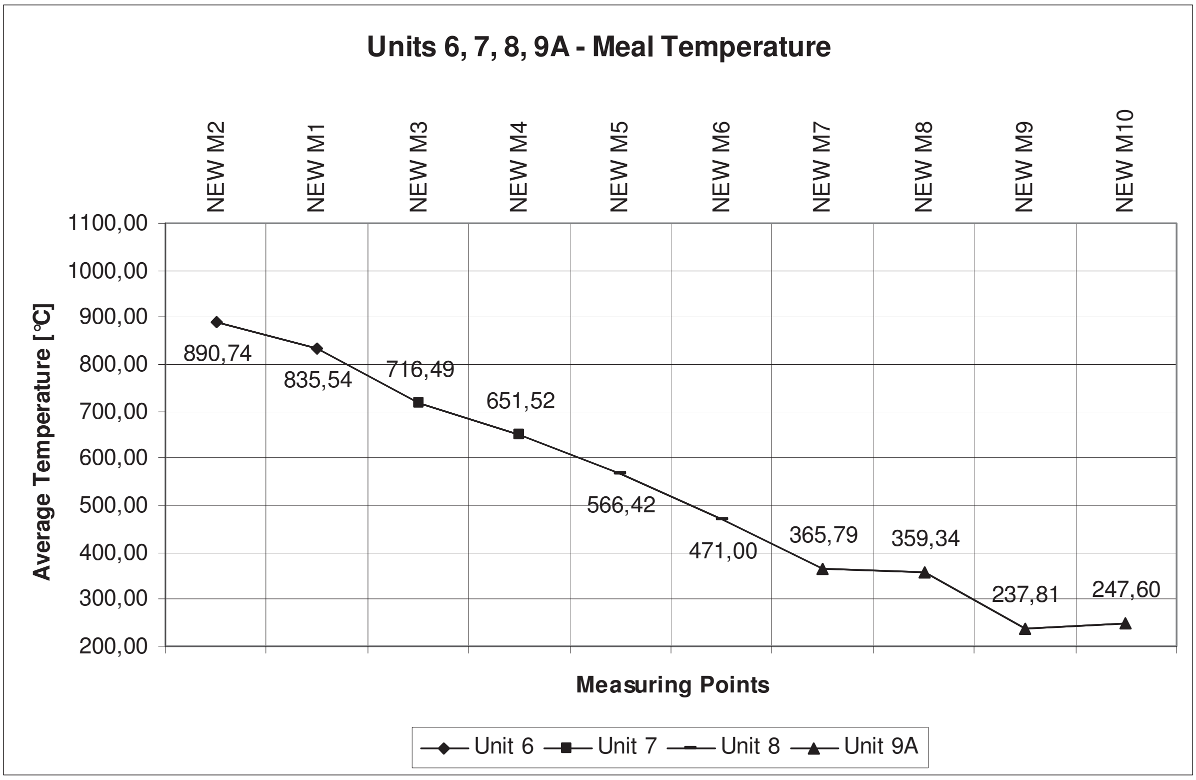

Figure 52: Units 6, 7, 8, 9A – Meal Temperature

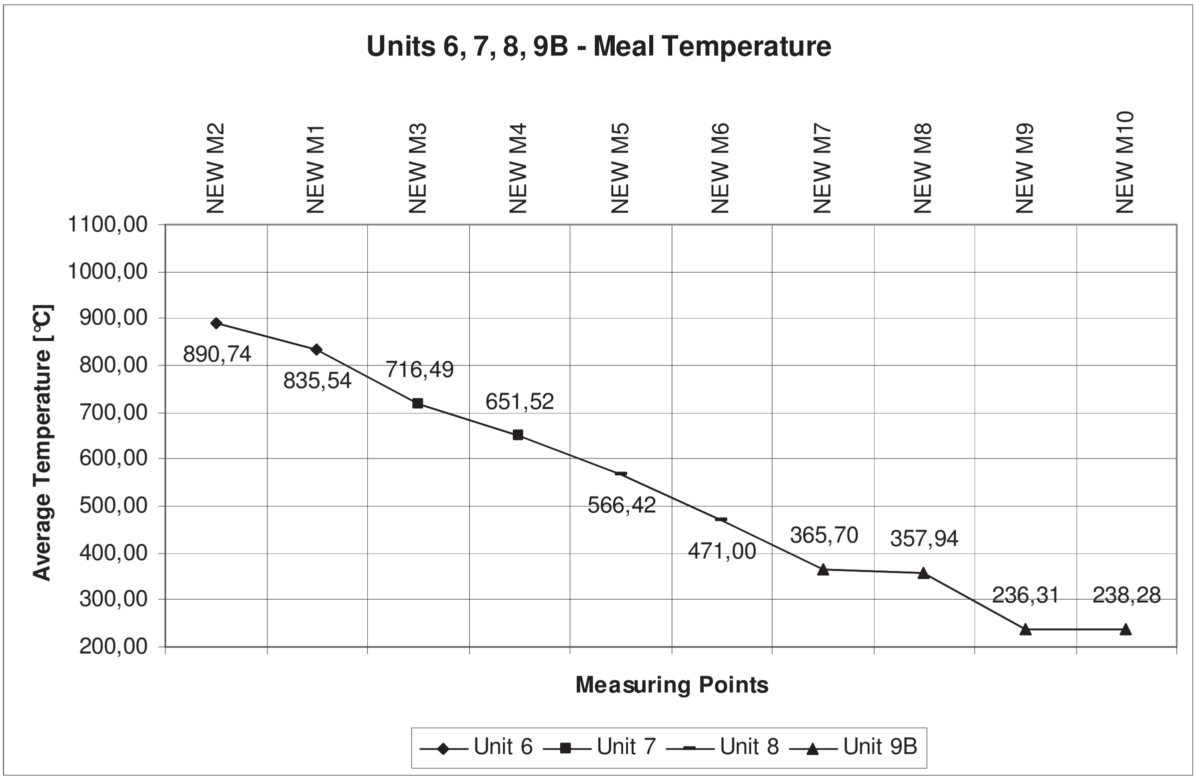

Figure 53: Units 6, 7, 8, 9B – Meal Temperature

7.5 Surface Temperature and Heat Loss

Table 30: Surface Temperatures and Heat Loss

Designation of Assembly		Surface Area	Average T	$\dot{Q}$	$\dot{q}$ per m²
		[m²]	[°C]	[kcal/kg_cli]	[(kcal/kg_cli)/m²]
C1	Top	110	81,38	0,31	0,0028
C1	Ellbow	0	45,00	0,00	0,0000
C1	Cyclon	505	51,58	0,64	0,0013
C2	Top	103	120,25	0,50	0,0048
C2	Ellbow	150	53,33	0,20	0,0014
C2	Cyclon	305	55,25	0,45	0,0015
C3	Top	116	130,25	0,62	0,0054
C3	Ellbow	155	72,00	0,36	0,0023
C3	Cyclon	342	74,31	0,84	0,0025
C4	Top	135	125,75	0,69	0,0051
C4	Ellbow	179	60,88	0,31	0,0018
C4	Cyclon	395	66,88	0,82	0,0021
K1	Top	99	69,50	0,22	0,0022
K1	Ellbow	0	49,00	0,00	0,0000
K1	Cyclon	430	42,69	0,35	0,0008
K2	Top	106	96,25	0,38	0,0036
K2	Ellbow	170	60,33	0,29	0,0017
K2	Cyclon	291	43,56	0,25	0,0009
K3	Top	130	141,50	0,77	0,0059
K3	Ellbow	160	75,33	0,40	0,0025
K3	Cyclon	325	71,38	0,75	0,0023
K4	Top	135	126,00	0,69	0,0051
K4	Ellbow	137	72,00	0,32	0,0023
K4	Cyclon	395	66,33	0,81	0,0020
KI		225	153,83	1,48	0,0066
CA		650	65,29	1,29	0,0020
RK1		235	45,56	0,23	0,0010
RK2		49	78,38	0,13	0,0027
RK3		255	93,44	0,88	0,0034
RK4		530	104,72	2,14	0,0040
RC1		425	60,44	0,74	0,0017
RC2		64	82,13	0,18	0,0029
RC3		65	122,63	0,32	0,0050
MPK0		28	44,75	0,03	0,0009
MPC0		24	37,50	0,01	0,0005
MPK1A		55	45,00	0,05	0,0009
MPK1B		55	45,25	0,05	0,0009
MPK2		44	61,50	0,08	0,0018
MPK3		44	118,75	0,21	0,0048
MPK4		74	102,75	0,29	0,0039
MPC1A		50	61,50	0,09	0,0018
MPC1B		53	63,00	0,10	0,0019
MPC2		42	79,00	0,11	0,0027
MPC3		97	114,75	0,44	0,0046
MPC4		67	169,38	0,49	0,0074
TOTAL		**8004**		**20,33**	**0,0025**

Description

C	Cyclones of Calciner String
K	Cyclones of Kiln String
RC	Riser Ducts of Calciner String
RK	Riser Ducts of Kiln String
MPC	Meal Pipes of Calciner String
MPK	Meal Pipes of Kiln String
CA	Calciner
KI	Kiln Inlet Chamber

Data and Formula

M	278792,00	[kg_cli/h]
α	16,82	[W/m²K]
Outside T	27	[°C]
v (wind) ~	3	[m/s]

$$\dot{Q} = \alpha * A * \Delta T$$

$$\alpha = 7{,}14 * v^{0{,}78}$$

Designation of assembly, surface areas and heat loss are shown in Table 30.

Due to the large surface area of the cyclones it is obvious that the values for heat loss are higher than for other elements of the preheater. As it can be seen in Figure 54 and Figure 55.

Distinctive feature is the heat loss for riser duct RK4 which heads the level of all calculation. High heat loss is also given for the calciner and the kiln inlet area. (Figure 55)

Figure 56 shows that the heat loss per square meter is very high at the top of the cyclones. On the one hand this area normally is a little bit hotter than other areas of the cyclones, on the other hand the heat loss is higher-than-average. Therefore thicker heat insulation or rather refractory should be used in future, according to the dew point. The next revision or maintenance should be considered for remodelling because the area of this surface is huge and can save running costs.

Extraordinary heat loss per square meter is given for the meal pipe MPC4, according to Figure 57. Daily problems with the flap of MPC4 force the maintenance group to clean the pipe from packing precalcined material with fresh air or even water. This work step destroys the refractory and does not guarantee good heat insulation. Further improvements are still necessary for construction design and maintenance.

High values for heat loss per square meter are noticeable for kiln inlet area KI, riser duct RC3 and meal pipes MPK3, MPK4, MPC3, according to Figure 57.

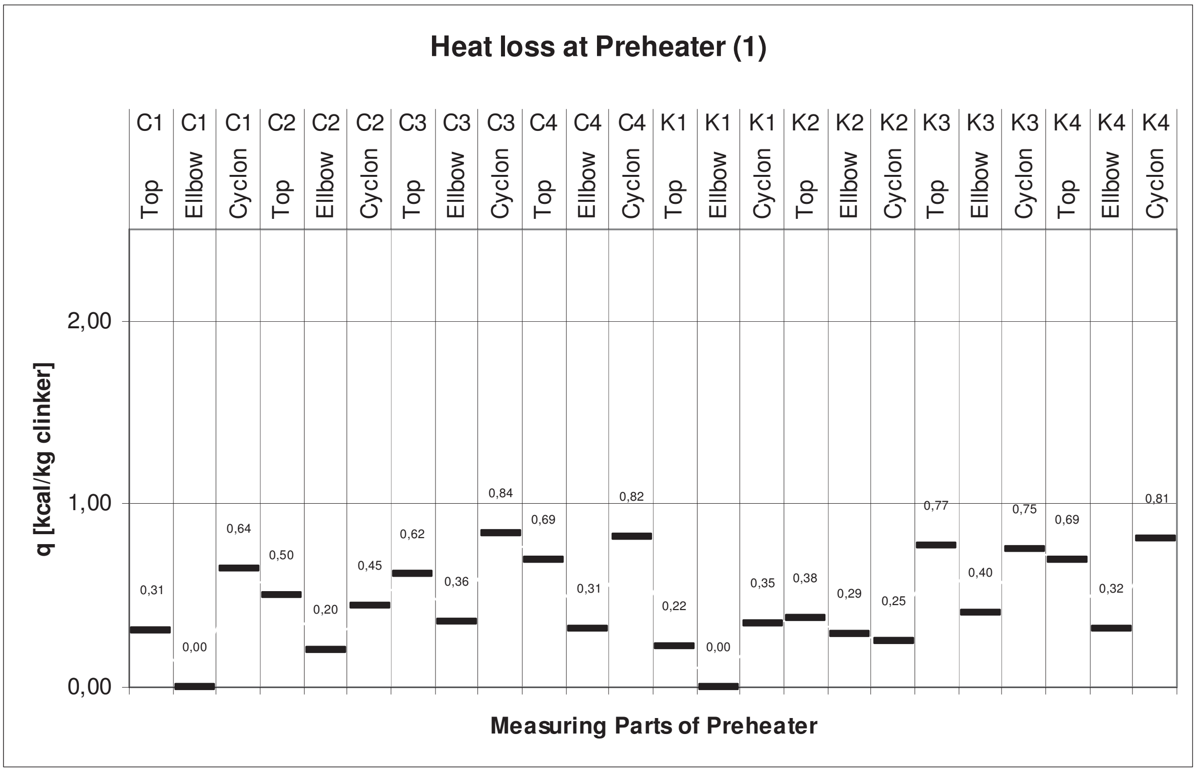

Figure 54: Heat loss at Preheater (1)

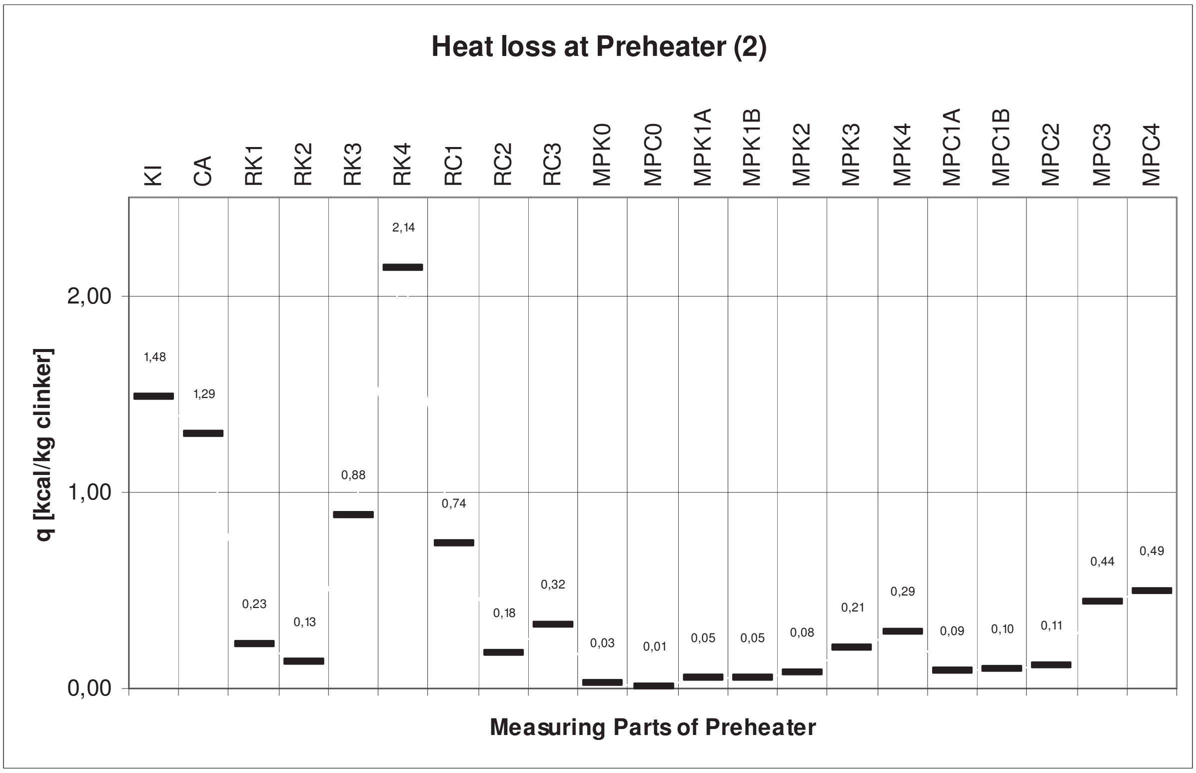

Figure 55: Heat loss at Preheater (2)

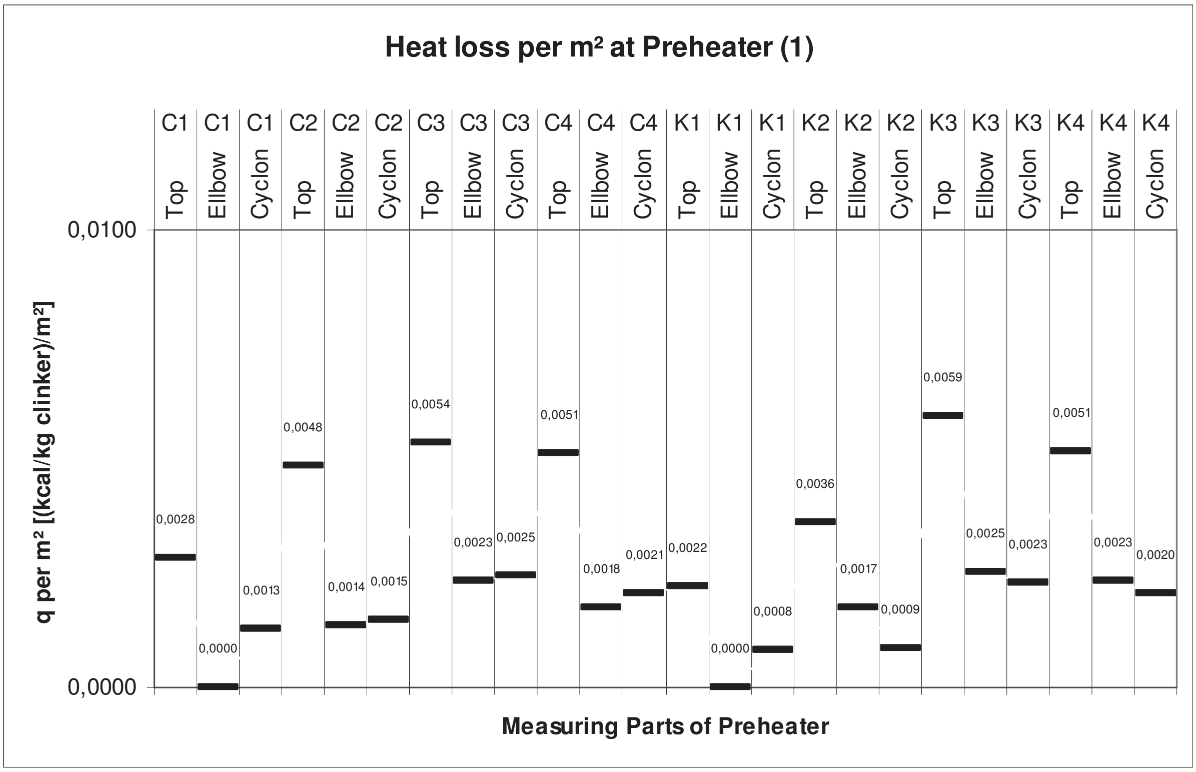

Figure 56: Heat loss per m² at Preheater (1)

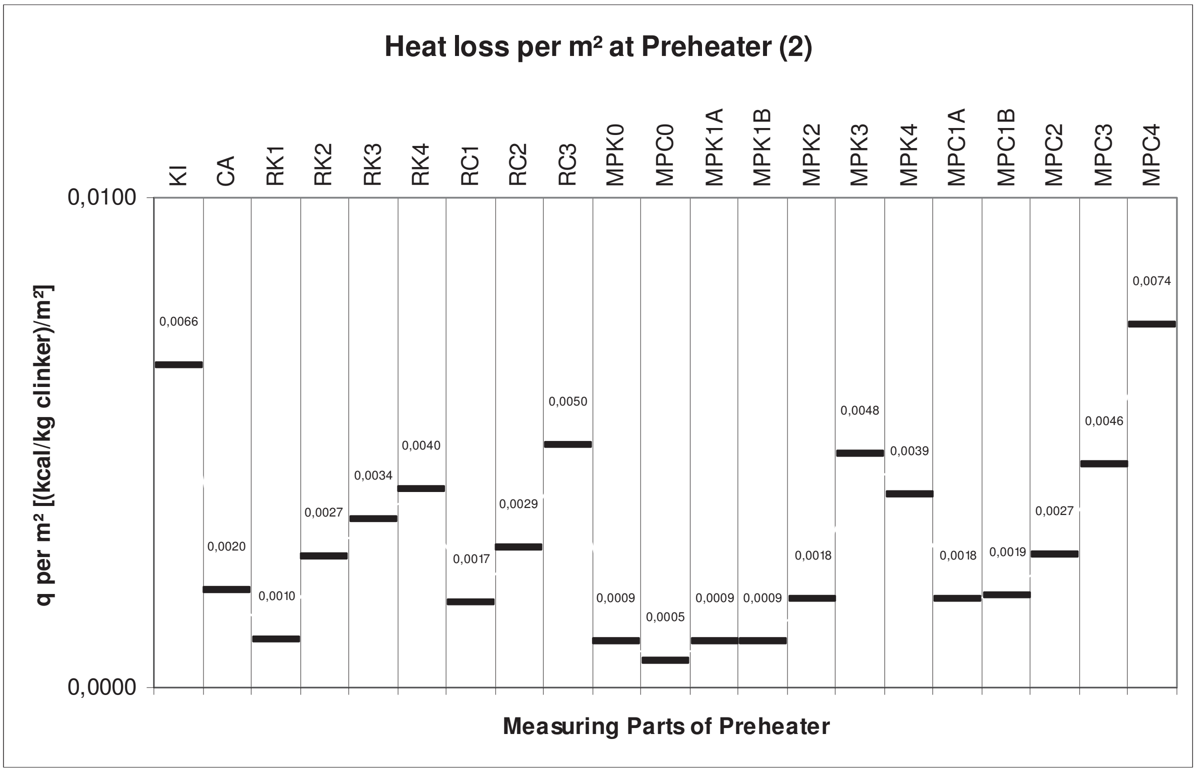

Figure 57: Heat loss per m² at Preheater (2)

7.6 Heat Transfer in Cyclones and Riser Ducts

For getting an overview about the heat transfer in cyclones and riser ducts a simplified calculation was prepared. Average values for density, specific heat capacity and volume flow of gas and raw meal mix are the basis to create below-shown graphical analyses. Therefore these results have to be handled with particular care.

The results of heat transfer bear resemblance to conclusions of temperature values, 330K4_TZ1 for instance or transition zone between NEW 8 and 330C3_TZ1.

According tables and figures: Table 31, Figure 58 till Figure 63

Table 31: Simplified Data for Calculation of Heat Transfer in Cyclones and Riser Ducts

Formula	Q = Rho*V*cp*(T2-T1)		
	[kJ] = [kg/m³]* [m³]*[kJ/kgK]*[K]		
Data for Calculation	Raw Meal Feed	460000	[kg/h]
	Clinker Production	278792	[kg/h]
	Rho	1,47	[kg/Nm³]
	V/2 [Total]	0,66	[Nm³/kg_cli]
	Cp	1,45	[kJ/kgK]

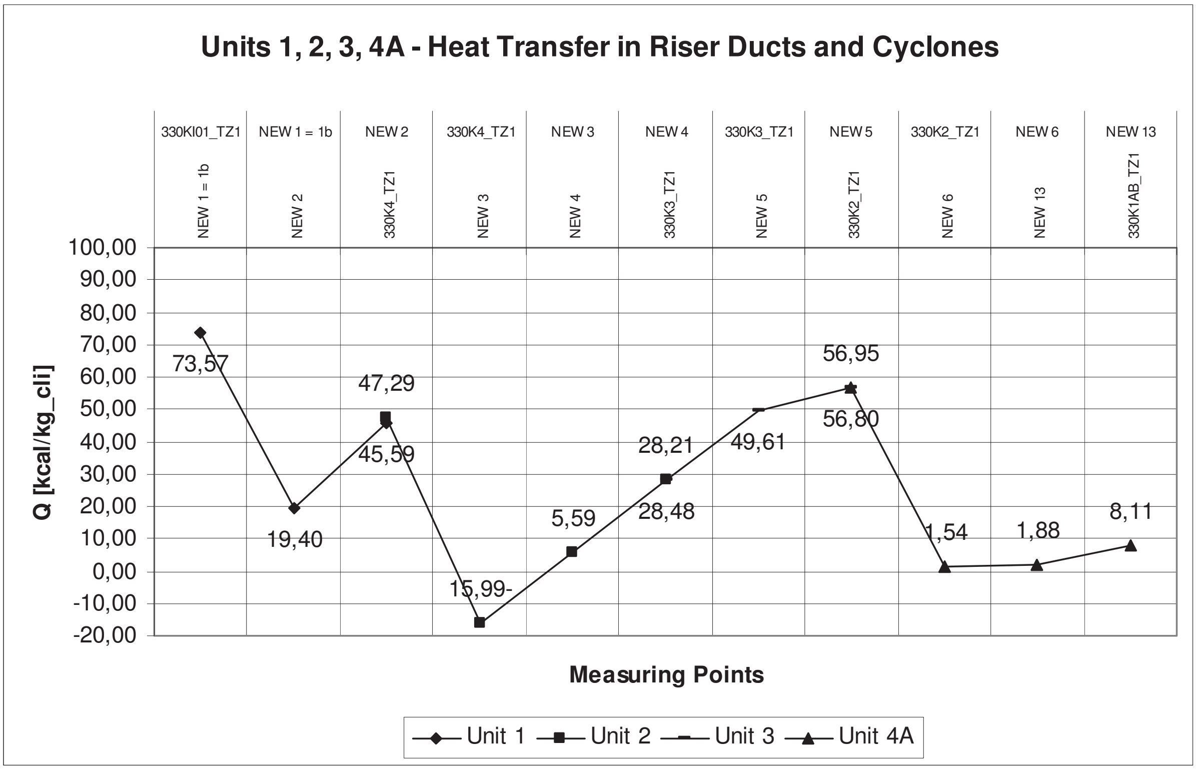

Figure 58: Units 1, 2, 3, 4A – Results of Simplified Calculation of Heat Transfer in Riser Ducts and Cyclones

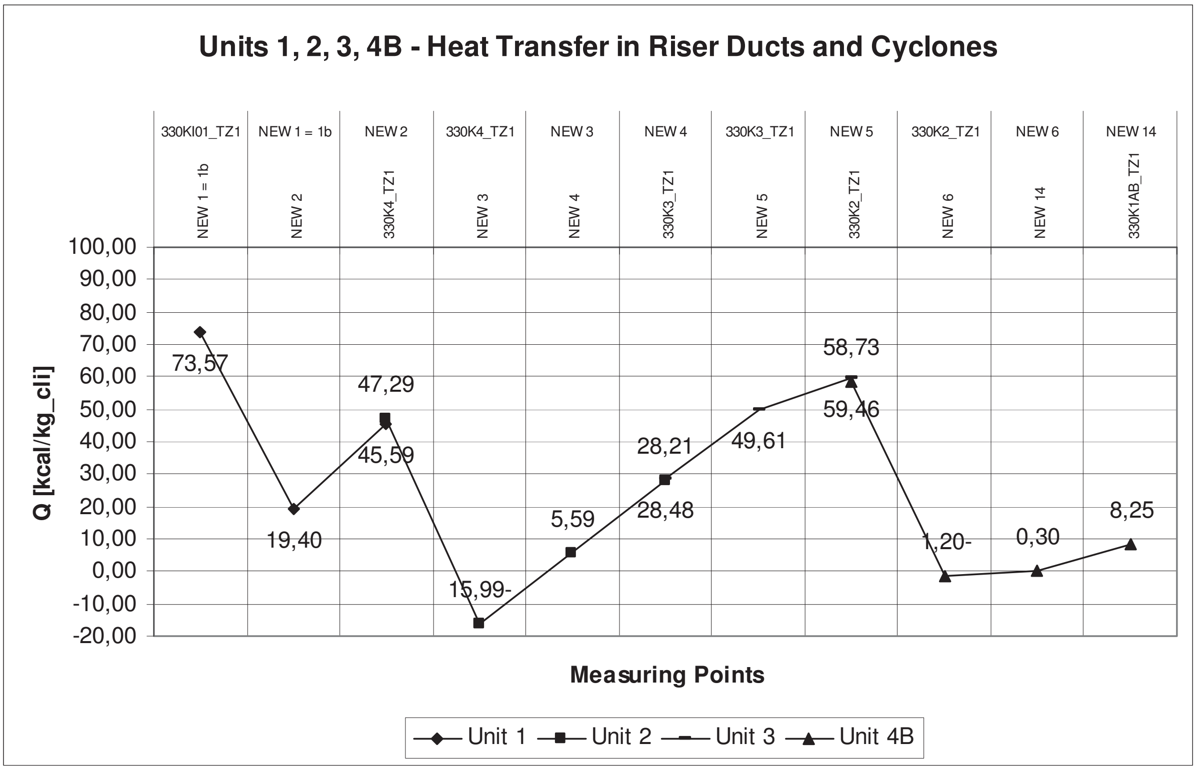

Figure 59: Units 1, 2, 3, 4B – Results of Simplified Calculation of Heat Transfer in Riser Ducts and Cyclones

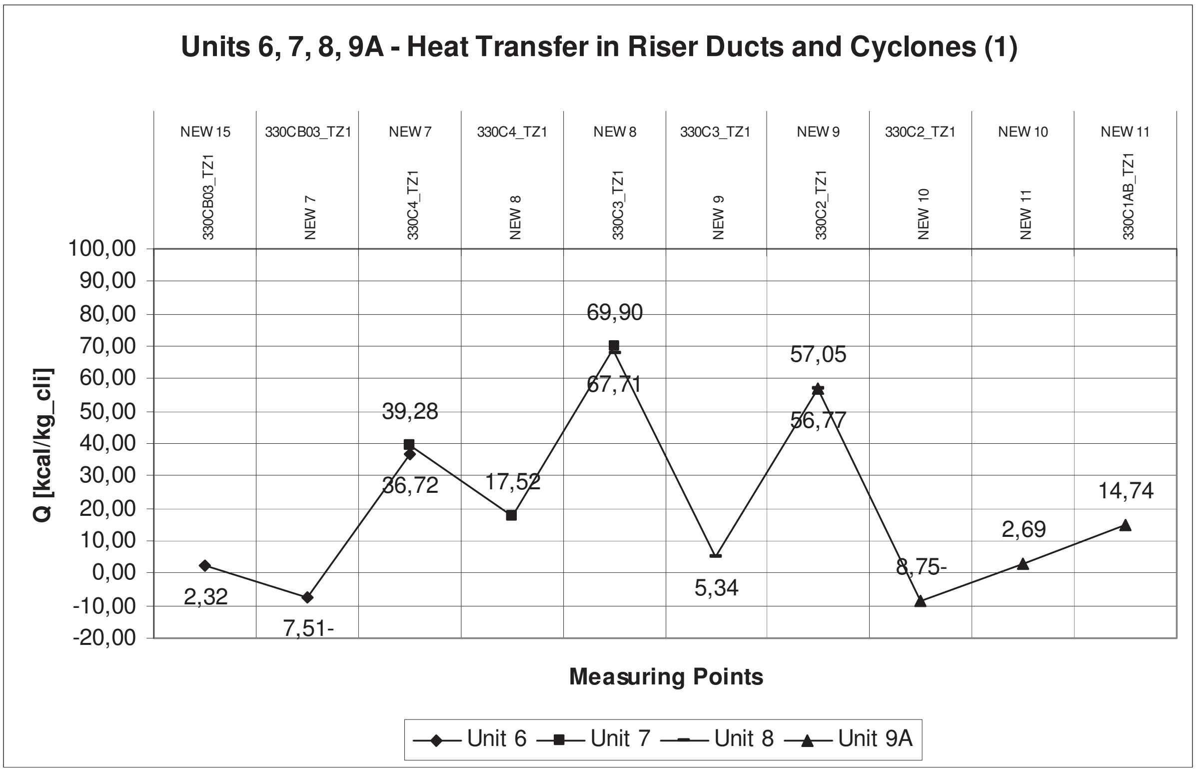

Figure 60: Units 6, 7, 8, 9A (1) – Results of Simplified Calculation of Heat Transfer in Riser Ducts and Cyclones

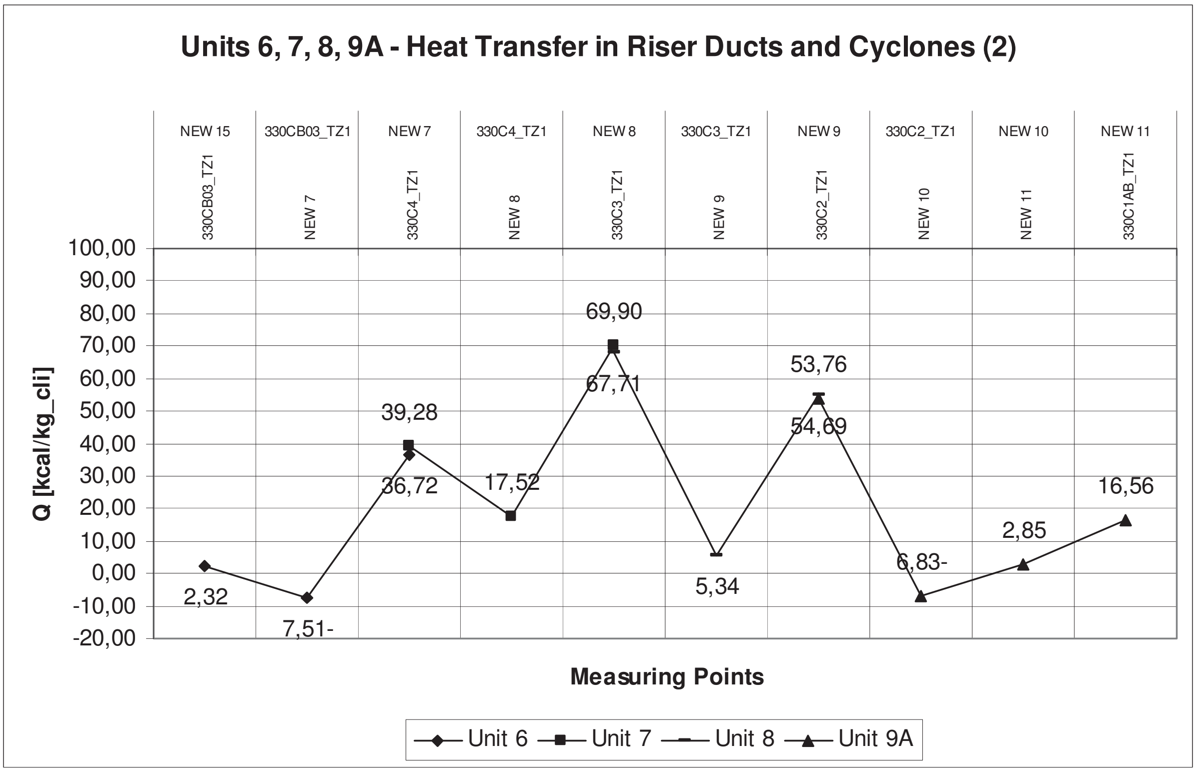

Figure 61: Units 6, 7, 8, 9A (2) – Results of Simplified Calculation of Heat Transfer in Riser Ducts and Cyclones

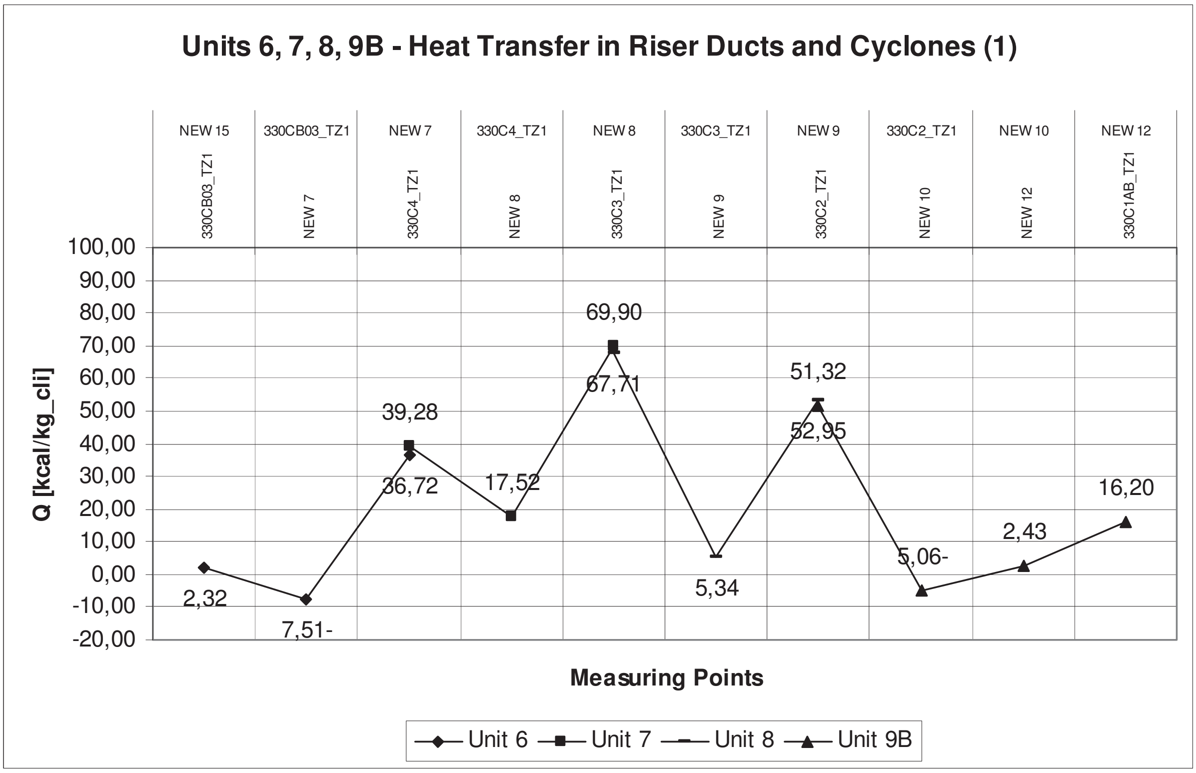

Figure 62: Units 6, 7, 8, 9B (1) – Results of Simplified Calculation of Heat Transfer in Riser Ducts and Cyclones

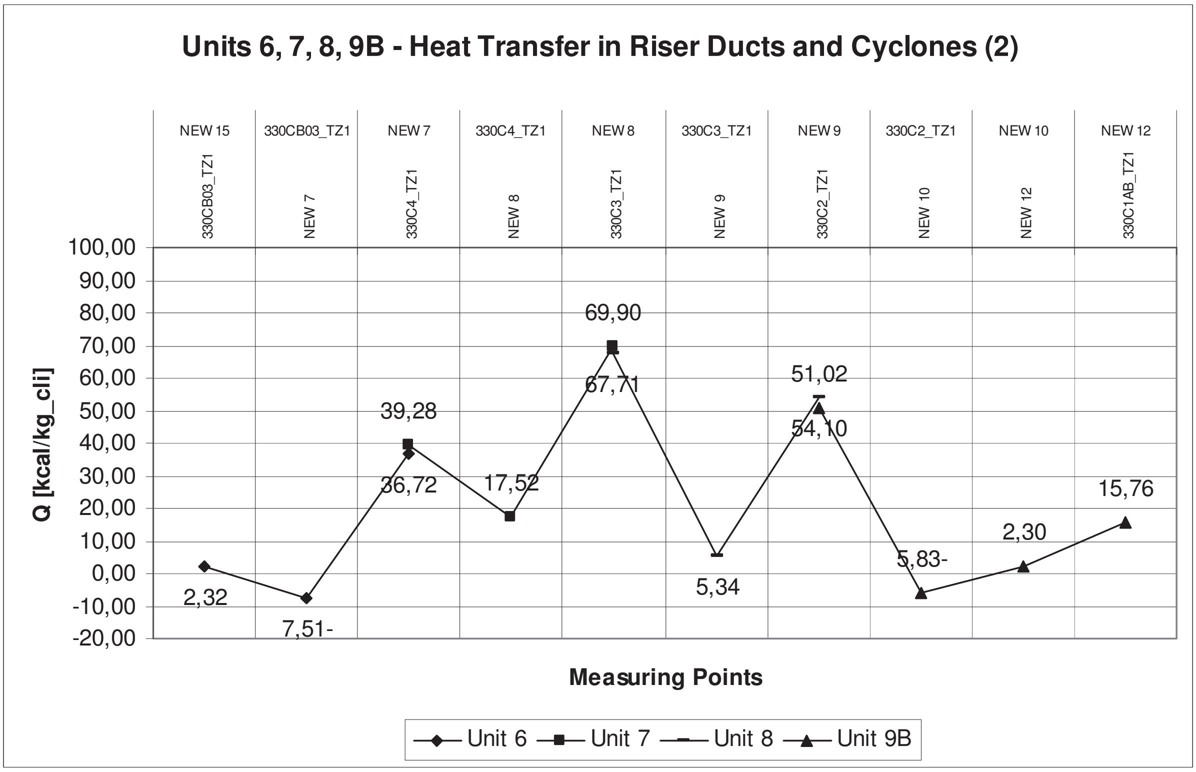

Figure 63: Units 6, 7, 8, 9B (2) – Results of Simplified Calculation of Heat Transfer in Riser Ducts and Cyclones

7.7 Heat of Raw Meal in Meal Pipes

Table 32 shows the values for calculation of heat of raw meal in meal pipes. Calcination degrees, specific heat capacities depending on temperature and according mass flows are taken into consideration.

A graphical visualisation of heat of raw meal in meal pipes is displayed in Figure 64.

Table 32: Heat of Raw Meal in Meal Pipes

Position	Calcined	T [°C]	cp [kJ/kgK]	m [kg]	Q [kJ]	Q [kJ/kg_cli]	Q [kcal/kg_cli]
NEW M2	85%	890,74	1,0987	313375	306671873	1100,00	262,72
NEW M1	27%	835,54	0,9976	420411	350440536	1257,00	300,21
NEW M3		716,49	1,0927	460000	360137229	1291,78	308,52
NEW M4		651,52	1,0818	460000	324223578	1162,96	277,75
NEW M5		566,42	1,0676	460000	278173242	997,78	238,30
NEW M6		471,00	1,0517	460000	227859084	817,31	195,20
NEW M7		365,79	1,0341	460000	174000770	624,12	149,06
NEW M8		359,34	1,0330	460000	170754930	612,48	146,28
NEW M9		237,81	1,0127	460000	110783685	397,37	94,91
NEW M10		247,60	1,0144	460000	115533700	414,41	98,97
NEW M11		74,21	0,9854	460000	33638096	120,66	28,82

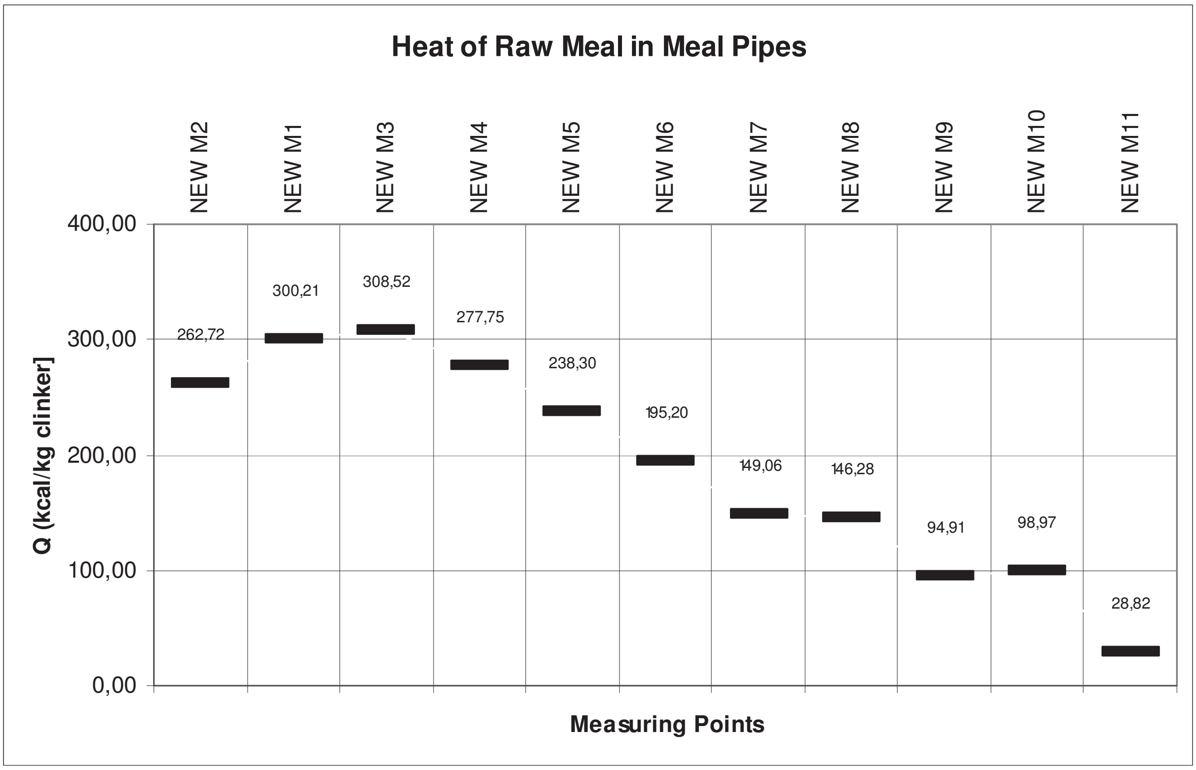

Figure 64: Heat of Raw Meal in Meal Pipes

7.8 Heat in Combined Unit 9A and Unit 9B

A different kind of calculation is done for Unit 9A and Unit 9B. Heat loss of surface and the influence of dust cycle in riser ducts and cyclones are not considered.

For this calculation the balance room with its limits is extended with rotary kiln and includes the combustion of total amount of fuel. This means combustion of coal at the main burner B3, secondary burner B2 and calciner burners B1a and B1b. Through theoretical calculation of exhaust gas from combustion of coal, decarbonisation and volatile components of raw material, furthermore a total gas analyse of mix gas including also false air is the basis for getting values for specific heat capacity.

The volume flow is calculated with data of just now mentioned total gas analyse and adapted to the fan data from calciner string. The values for density of mix gas conform to experience of ÖMAG-Montananlagenbau GmbH.

The values for temperature of measuring points are based on average results of measurement.

Attention should be paid to recognizable heat transfer between measuring points M7, M8 and M9, M10.

According Tables and Figures: Table 33, Figure 63, Figure 64

Table 33: Heat in Combined Unit 9A and 9B

Position	Rho of Mixgas [kg/m³]	V (46% of Total) [Nm³/h]	cp [kJ/kgK]	Average T [°C]	Q [kJ]	Q [kJ/kg_cli]	Q [kcal/kg_cli]
NEW 9	1,46	168474,06	1,5681	513,26	197972711	47282711	169,60
330C2_TZ1	1,45	168474,06	1,5250	353,90	131842247	31488476	112,95
NEW 10	1,45	168474,06	1,5394	373,69	140528391	33563026	120,39
NEW 11	1,45	168474,06	1,5250	366,24	136439159	32586377	116,88
330C1AB_TZ1	1,44	168474,06	1,5106	318,72	116805371	27897151	100,06
Position		**T [°C]**	**cp [kJ/kgK]**	**m [kg]**	**Q [kJ]**	**Q [kJ/kg_cli]**	**Q [kcal/kg_cli]**
NEW M7		460000	1,0341	365,79	174000770	624,12	149,06
NEW M8		460000	1,0330	359,34	170754930	612,48	146,28
NEW M9		460000	1,0127	237,81	110783685	397,37	94,91
NEW M10		460000	1,0144	247,60	115533700	414,41	98,97

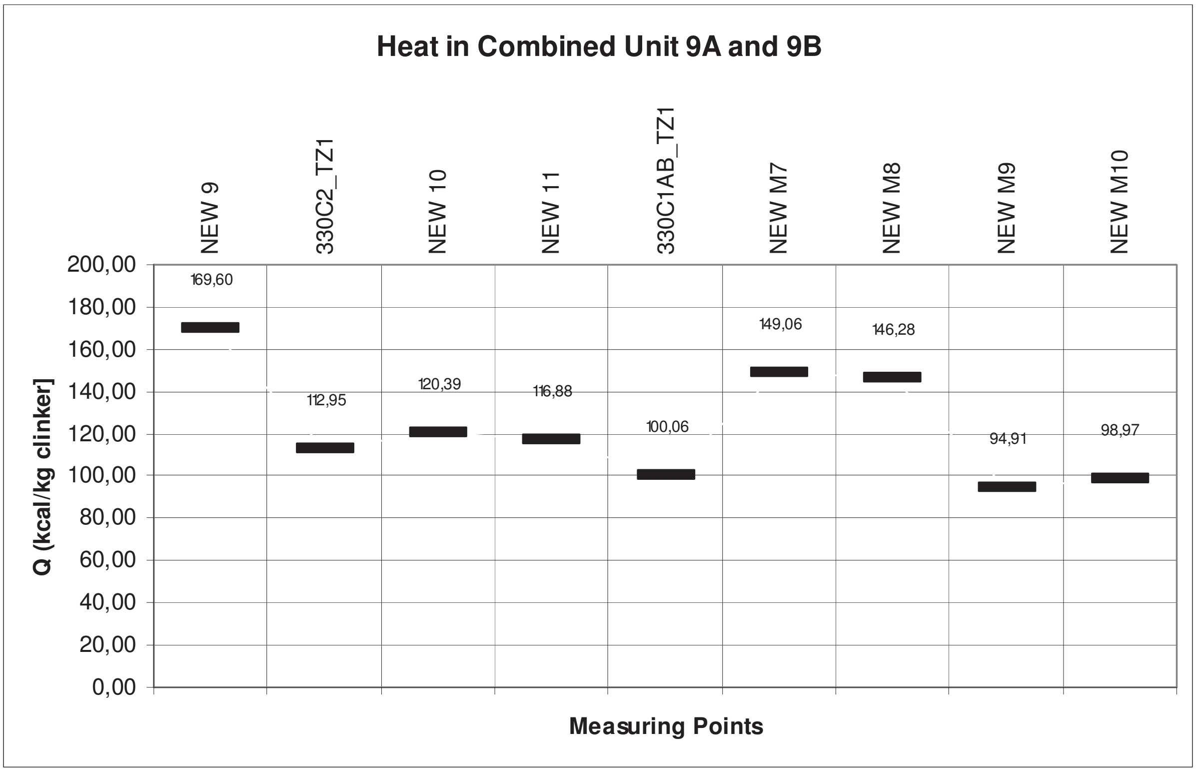

Figure 65: Heat in Combined Unit 9A and 9B

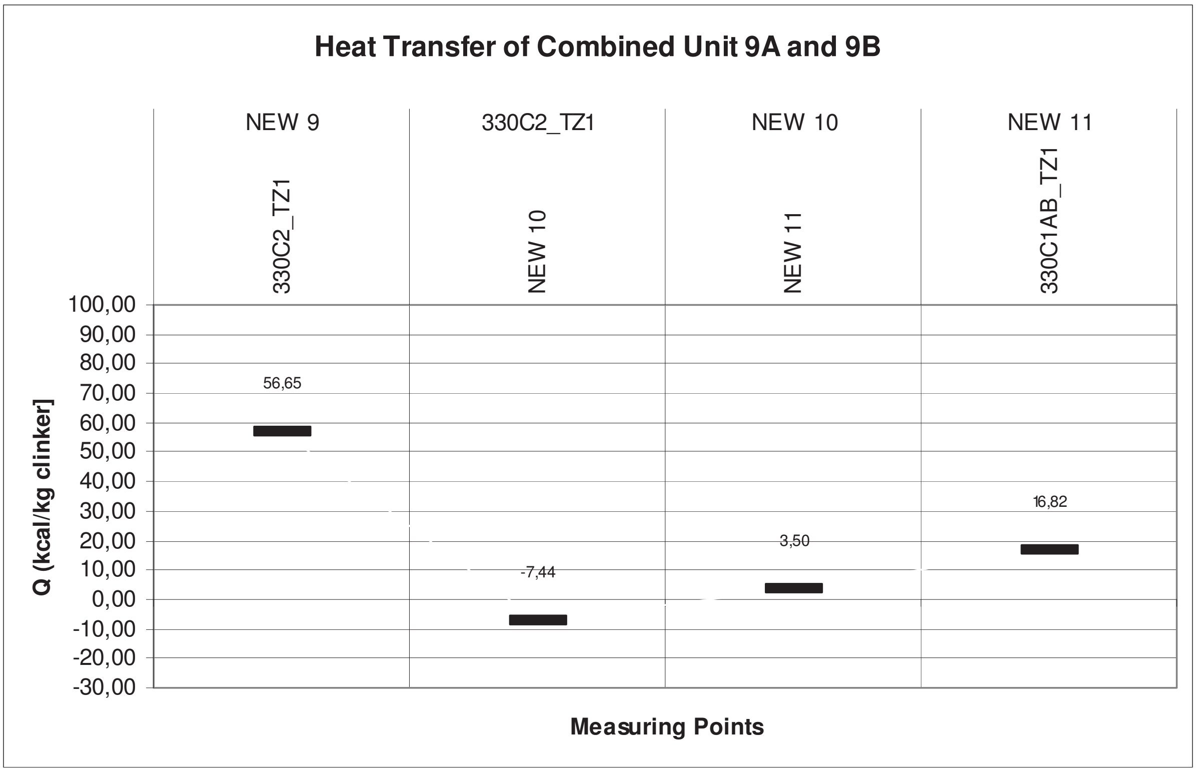

Figure 66: Heat Transfer of Combined Unit 9A and 9B

8 Conclusions and Outlook

8.1 General Annotations

The results of this project and the attained knowledge provide a basis for more precise detail knowledge of such a large ÖMAG preheater and precalcining system. Several additional measuring points show characteristics of material and gas flow in more detail.

Previously unverified process parameters like temperature and pressure at decisive points are recorded simultaneously and sequenced data should enable ÖMAG-Montananlagenbau GmbH to work on future improvements.

Chapter 6 and 7 feature an overview about temperature, pressure and technical heat calculations. Strong and weak points are also indicated there.

8.2 Assembly of Measuring

The classification of the measuring units and the idea of simultaneous measurement was a correct approach for getting more information about the new 7,000 tpd ÖMAG 1® suspension preheater.

8.3 Execution of Measuring

Due to the complexity of the developed measuring system the measuring equipment is sensible for technical interferences. Extension and connection cables caused many defective contacts. Therefore measurements had to be repeated.

However, the execution of measuring was feasible and the pointed aim to record all required data was achieved.

8.4 Measuring Data

As a result of recording measuring data every second, the amount of data taken from the MIS – Management Information System is very high. (MIS is a data base which is recording measuring data of the current process in a cement company.) The combination of measured data by hand and retrieving data from the MIS was time consuming. Furthermore the adjustment and calculation (reference to 5.3 Modified Measuring Methodology) has cost the most time of the analyses. If the measuring values of the existing thermocouples had been correct, most part of the temperature measuring and analysing work would not have been necessary.

8.5 Discussion of Measuring Results

The measuring results of surface temperatures indicate that high heat losses per square meter are given for kiln inlet area KI, riser duct RC3 and meal pipes MPK3, MPK4 and MPC3 and exceedingly high for MPC4. In addition, the upper parts of the cyclones, especially of cyclones C2, C3, C4 and K2, K3 and K4 loose a lot of heat per square meter.

Generally considered, the highest heat loss through surface occurs at riser duct RK4, followed by kiln inlet KI and calciner CA.

The gas temperature values represent normal characteristics, with the exception of measuring point 330K4_TZ1 (explanation see below). Constant heating of raw meal was noticed without any irregularities and verified with the measuring results.

Measuring results for pressure and calculated pressure losses are in the range of normal values. High pressure loss was ascertained for the transition zones between measuring points NEW 1 and NEW 2, as well as between NEW 6 and NEW 13 or rather NEW 14. Furthermore, considerable decrease in pressure can be seen in the transition zone between 330C2_PZ1 and NEW 10. These facts are not extraordinary because they are based on the design of the preheater tower.

High heat transfer in riser ducts and cyclones was diagnosed for the transition zones 330KI01_TZ1 and NEW 1, NEW 2 and 330K4_TZ1, NEW 5 and 330K2_TZ1, NEW 8 and 330C3_TZ1 as well as NEW 9 and 330C2_TZ1.

8.6 Outlook

First actions should be taken in installation of better heat insulation for the roofs of the cyclones because a high heat loss is experienced in these areas.

More attention should be paid on future maintenance works like replacement of used thermocouples: Correct installation of new thermocouples is necessary for getting accurate measuring values. For instance, measuring data of MIS of measuring points 330C4_TZ1 (located at riser duct RC3) and 330CB01_TZ1 (located at riser duct RK4) deviated notable from those of mobile measuring equipment by TESTO and BEAMEX. Causes for those deviations are missing cold junction compensation boxes, wrong programming of transmitters and influences on compensating cables by electric power lines.

A known problem with meal pipe MPC4 is obvious and mirrors too high expenses for maintenance and workers. Packing precalcined material blocks the meal pipe which is cleaned with cold air and water. This fact leads to high heat loss.

Unsteady and impulse-type combustion of coal is ascertainable under operating conditions. This fact leads to considerable fluctuations of temperature values. In this paper not-mentioned gas analyses in riser duct RC4 and RC3 show that measurement values of CO are subject to high variations.

Long-term modifications of the position of existing measuring points could help for getting better measuring results which are recorded by the MIS – Management Information System. Measuring point 330K4_TZ1 normally indicates values for gas temperature. But in this case the value of temperature is too low because the position of the thermocouple is very close to meal pipe MPC2 (which enters the riser duct RC3). Explanation therefore is that cold raw meal in meal pipe MPC2 crosses the thermocouple.

As a final remark it can be said that a lot of measuring data is collected for further verification of the theoretical company-internal calculation. Improvements on geometrical design might lead to more efficient heat balance, less pressure loss and therefore to better cost efficiency of running cement production.

9 Directories

9.1 References

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9.2 List of Abbreviations

°C	degree Celsius
mV	millivoltage
mm.	millimeter
m	meter
m^2	square meter
m^3	cubic meter
t	ton
V	volume
m	weight
cp	specific heat capacity at constant pressure
p	pressure
t	temperature
kg	kilogram
J	joule
cal	calorie
k	kilo
Q	heat
Hu	net calorific value
K	kelvin
W	watt
v	velocity of wind
A	area
s	second
h	hour
d	day
RPM	round per minute
Nm^3	norm cubic meter
Rho	densitiy
V	volt
mV	millivolt
µ	mykro
A	ampere
mA	milliampere
Pa	pascal
hPa	hectopascal
bar	bar
mbar	millibar
$\dot{Q}$	heat flow

9.3 List of Tables

9.4 List of Figures

Appendix

The Appendix contains:

- Verification of Measuring Equipment, dated 14.7.2006
- Verification of Measuring Equipment, dated 18.7.2006

14.07.2007 Verification of Measuring Equipment										
Pos.	**Thermocouple**			**Time**	**Testo 454**	**Beamex TC 305**	**CCR**	**E. Transm.**	**E. Transm.**	**Comments**
	[No.]	**[No.]**	**[No.]**	**[1]**	**[°C]**	**[°C]**	**[°C]**	**[mV]**	**[°C]**	**[1]**
RK1	**330**	**K2**	**TZ1**	**09:13**	238	238	222			Reckmann GmbH
					245	244				1xNiCr-Ni Typ K
					243	243				D-58137
				09:17	242	244	222,5			
				09:22					240,7	
								8,79		
ID	**330**	**K1A/B**	**TZ1**	**09:31**			211	8,2	230	1xNiCr-Ni Typ K
								8,2		Product?
								8,33		
ID	**330**	**C1A/B**	**TZ1**	**09:39**	348	343				Reckmann GmbH
					349	347				1xNiCr-Ni Typ K
					349	347	326		347,2	
								13,13		
RK2	**330**	**K3**	**TZ1**	**09:52**	492	473	460			Elimko
				09:57	495	480	461,7			Series 06/2678
				09:58	494	472	461,8		490	Tip: TC01-1K2N22-120-PY
								19,128		1xNiCr-Ni Typ K
				09:55	*486*	*479*				*Testo with 2 thermo-couples*
RC1	**330**	**C2**	**TZ1**	**10:06**	370	374	346,7			Elimko
					372	376				Series 06/2678
					379	380				Tip: TC01-1K2N22-120-PY
				10:07	380	382	347,7			1xNiCr-Ni Typ K
				10:08	379	383	347			
					374	377				
					376	378				
				10:10					369	
								13,968		
RC2	**330**	**C3**	**TZ1**	**10:18**	578	574	537,1			Siemens
					580	576				1xNiCr-Ni Typ K
					576	574				Series:1807/06
				10:19	577	573	536,4			
					578	574				
					576	573				
				10:21			536,8		557,9	
								22,006		
RC3	**330**	**C4**	**TZ1**	**10:30**	709	688	640			Elimko
					707	687				Tip: TC01-1K2N22-120-PY
					705	686				
				10:32	716	692	640,7			
					719	694				
					696	677				
				10:33	708	678	640,6			
				10:34			641,3	27,32	680	
									681	
								27,352	682	
									683	
								27,376		
								27,396		
								27,428		
				10:36			647,6	27,488		
								27,502		
								27,52		

RK3	**330**	**K4**	**TZ1**	**10:41**	627	613	587,1			Meter
					630	614				1xNiCr-Ni
					628	614				Series: 1798/06
					630	614				
					627	613				
				10:42	629	615	586,1			
					634	617				
					633	618				
				10:43	628	616	587,1			
					626	613				
					629	613				
				10:44			588,2		622	
									622	
									622	
								24,658		
								24,66		
								24,662		
								24,666		
								24,67		
RK4	**330**	**CB01**	**TZ1**	**10:51**	822	806	751,7			Elimko
					823	804				Tip: TC01-1K2N22-120-PY
					823	804				
					823	803				
					823	802				
				10:53	823	798	751,7			
					823	796				
					822	797				
				10:55			751,4		792	
									793	
									794	
									795	
									795	
									796	
				10:57			757,6	31,875		
								31,885		
								31,9		
								31,93		
								31,93		
								31,94		
								31,94		
				10:58			758,7	32,035		
								32,04		
								32,04		

RC4	**330**	**CB01**	**TZ1**	**11:02**	888	890	881,5			Meter
					888	892				Serie 1800/06
					884	890				
					885	892				
					890	890				
					882	890				
				11:04	897	899	878,1			
					889	895				
					884	892				
				11:05	882	890	871,9			
					897	897				
					894	897				
				11:06			871,2		894,8	
									894,7	
									894,7	
								35,85		
								35,845		
								35,84		
				11:07			871,5	35,835		
								35,83		
								35,835		
TA-Duct	**331**	**TA**	**PZ1**	**11:13**	919	902	851			Elimko
					918,7	901,7				Serie 05/20269
					918,1	900,8				Tip: TC01-1K2N22-120-PY
					917,4	900				
					916,6	899				
					916,3	898,3				
					916	897				
				11:15	915,7	897,2	853			
					915,8	897				
				11:18			854,1		889,9	
									890,7	
									891,2	
									891,7	
									891,9	
									892,2	
								35,805		
								35,815		
								35,825		
								35,835		
								35,845		
								35,86		
								35,865		
								35,895		
								35,915		
								35,94		
				11:20			854,5	35,01		
								36,015		
								36,02		
								36,025		
								36,04		
				11:21			853,8		900,6	
									900,8	
									900,7	

18.07.2007 Verification of Measuring Equipment											
Pos.	Thermocouple			Time	Testo 454 short	Testo 454 long	Beamex TC 305	CCR	E. Transm.	E. Transm.	Comments
	[No.]	[No.]	[No.]	[1]	[°C]	[°C]	[°C]	[°C]	[mV]	[°C]	[1]
RC3	330	C4	TZ1	13:32	28,47			696	28,87		Elimko
									28,776		Tip: TC01-1K2N22-120-PY
									28,774		
				13:33				699		715,3	
										715,2	
										715,3	
				13:48	29,6						
					28,6						
					28,63						
					28,39						
					28,75						
					28,86						
					28,53						thermo-couple ~2mm dust
					28,4						
					28,6						
				13:51	728			700			
					715						
					728						
					732						
					724						lot of wind!!!
					723						
					728						
				13:52			29,7	701			
							29,48				
							29,35				
							29,38				
							29				
							30				
							29,7				
				TESTO	short						
				13:53	705/737	705		702			
					714/742	714					
					713/735	713					
					--/29,97						
					--/29,75						
				13:54	--/734			703	28,78		
									29		
									28,89		
									28,75		
									28,64		
									28,626		
				13:59	714/744	714	696	705			
					715/739	715	694				
				14:00	717/738	717	695				
							698				
				14:02	714/734	714	681,5				
				14:03	716/737	710	691				
				14:04	710/724	710	689				
				14:06	28,77/--			706,6			
					28,85						
					29,03						
					28,89						
					29,1						
				14:07	708=29,30	708		708			
					710=28,82	710					
					719=28,88	719					
					717=28,79	717					
					713=28,50	713					
					720=29,20	720					
					721=29,05	721					
					717=28,85	717					
				14:28				711			

RK3	**330**	**K4**	**TZ1**	**14:25**	632/629	632	625	615			Meter
				14:26	631/627	631	627				1xNiCr-Ni
				14:27	633/630	633	629	616			Series: 1798/06
				14:28	624/622	624	24,91				
				14:29	624/622	624	24,89	616			
				14:35	627/624	627	24,96	616			
				14:38	625/624	625	24,95				
				14:41	630/629	630	25,034				
				14:42	634/630	634		616,5	25,112		
									25,102		
					632/631					630	
					635/631					630,7	
				14:44	628/626	628					
				14:47				616,6			
RK4	**330**	**CB01**	**TZ1**	**14:59**	815/816	815		790			Elimko
					813/814	813					Tip: TC01-1K2N22-120-PY
				15:02	816/817	816		794		810	
					817,4/818,3	817				811,7	
				15:03	815/817	815		795		810	
				15:04	816/817	816				808	
				15:05	815/816	815				806	
				15:08*	807=32,445			796			*long testo t-couple
					806=32,445						with Beamex evaluation
					805=32,420						
				15:11					32,65		
									32,655		
				15:12					32,655		
TA-Duct	**331**	**TA**	**TZ1**	**16:35**	930/929		911,2	872			Elimko
				16:36	931/929		911,3				Serie 05/20269
				16:37	930/929		912				Tip: TC01-1K2N22-120-PY
					931,5/930,2		912,6				
				16:38	932/930,8		912,5				
				16:39	930,5		928,9	872			
				16:40			36,65				
							36,36				
							36,375				
							36,415				
							36,505				
							36,555				
					--/928		36,71				
					931,4/930		36,8				
					932,6/930,8		36,76				
				16:42	928/932			872			
					37,12						
					37,115						
					37,11						
				16:43	37,045						
					37,07						
					37,14						
				16:44	37,2						
					37,21			877			
					37,195=928,5						
				16:45				888		919	
										920	
										921	
				16:46	--/939,5			892	37,385		
					--/939				37,44		
									37,48		
				16:47	--/939			900	37,5		
					--/940				37,535		
					--/940,2				37,545		
					--/940,6				37,57		