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Evaluation of Noise and Vibration in Boilers at High Loads

تقيم الضوضاء والإهتزاز في المراجل عند الأحمال العالية

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بسم الله الرحمن الرحيم

قال تعالي :-

(قُل لَوْ كَانَ الْبَحْرُ مِدَادًا لِّكَلِمَاتِ رَبِّي لَنَفِدَ الْبَحْرُ قَبْلَ أَن تَنفَدَ كَلِمَاتُ رَبِّي وَلَوْ جِئْنَا بِمِثْلِهِ مَدَدًا)

صدق الله العظيم

DEDICATION

It is our genuine gratefulness and warmest regard that we dedicate this work to my Mother and wifes; whose are encouraged me all the way and whose encouragement has made sure that I give it all it takes to finish that which I have started. To all my children whose have been affected in every way possible by this quest. Thank you. My love for you all can never be quantified. God bless you.

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This work would not have been possible without the fully support of the Khartoum North Power Station. I am especially indebted to Engineer Abdelaziz, Section head of maintenance department, who have been supportive of me and worked actively to provide me with all information and data on time to pursue those goals. I am grateful to all of those with whom I have had the pleasure to work during this project. Each of the members of my Teachers has provided me extensive personal and professional guidance and taught me a great deal about both scientific research and life in general. I would especially like to thank Dr. Hassan A/Latif Osman, the supervisor of me as my teacher and mentor, He has taught me more than I could ever give him credit for him.

ABSTRACT

Various components inside the boiler are required to promote efficient combustion and heat transfer. Their design depends on factors such as the type of fuel and the method selected to transfer thermal energy. The maximum power output from any thermal power plant is top priority for engineers, and maximum power output means maximum loads which related to maximum fuel consumption and air flow control system (A/F ratio). Vibration and noises resulted from the over dose of air –fuel ratio in boilers is the main consideration of this research project. The demands for electricity in peak-loads generate an unacceptable noise and vibration. This research tries to find a solution for noise and vibration in the boilers when operate on high load with high efficiency and safe mode for tools and operators.

Physical measurement of the vibrations in the boilers by measuring probes is difficult in the running boiler due to high temperature. So, there is a need to evaluate vibrations in affected regions theoretically. Computational Fluid Dynamics (CFD) tools have been found appropriate to perform the flow analysis. Owing to recent improvements in CFD and by analysis the type of air flow in the boilers component of air duct, wind-box and burners we found the flow induced is the source of the noise and vibration, to reduce the effect of flow induce inside the boiler system we used CFD modeling and by partition of the duct of the inlet air for boiler number 5 by sheet metal and run ANSYS software before and after partition the flow dramatically change after partition, then the solution install in boiler number 5 therefore the problem was totally solve and the boiler operate with standard levels of noise and vibration. The recommendation is to implement the same solution of partition in boiler 3 &4 when the system is ready for installation of partition in the wind-box before burners the flow induce will be eliminated and the boiler will operate on the high load without noise and vibration.

مستخلص

مطلوب مكونات مختلفة داخل المرجل لتعزيز كفاءة الاحتراق ونقل الحرارة. تصميمها يعتمد على عوامل مثل نوع الوقود والطريقة المختارة لنقل الحرارة. إن أقصى إنتاج للطاقة من أي محطة طاقة حرارية هو أولوية قصوى للمهندسين، ويعني أقصى إنتاج للقدرة لمقابلة الأحمال القصوى التي تتعلق بأقصى استهلاك للوقود ونظام التحكم في تدفق الهواء (نسبة A / F). الاهتزاز والضوضاء الناتجة عن الجرعة الزائدة من نسبة الهواء في المراجل عند زيادة الأحمال الي أقصى طاقة هي الداعي الرئيسي لهذا المشروع البحثي. ويحدث نتيجه للطلب على الكهرباء في اوقات أحمال الذروة ضجيجا واهتزازا غير مقبولين. ويحاول هذا البحث إيجاد حل للضوضاء والاهتزازات في المراجل عند تشغيلها في احمال عالية وذلك وفق كفاءة عالية ويحفظ سلامة المعدات والمشغلين.

القياس الفيزيائي للاهتزازات في المراجل من خلال اجهزه القياس من الصعب تحقيقها اثناء التشغيل بسبب الارتفاع في درجة الحرارة. لذلك هناك حاجة لتقييم الاهتزازات في المناطق المتضررة نظريا. مما تعتبر نمذجة ديناميكا الموائع (CFD) من الأدوات المناسبة لإجراء تحليل التدفق الهوائي. وبسبب التحسينات الأخيرة في حوسبة ديناميكا الموائع ، ومن خلال تحليل نوع تدفق الهواء في اجزاء المرجل فقد وجدنا الجرعه الزايده من تدفق الهواء هو السبب الرئيسي للمشكلة وللحد من تاثير الجرعة الزايده داخل نظام المراجل استخدمنا برنامج نمذجة ديناميكا الموائع (CFD) وقمنا بتقسيم مجرى الهواء عند مدخل المرجل رقم ٥ بواسطة صفيحه معدنيه وتشغيل برنامج ANSYS قبل وبعد التقسيم تغير سريان الهواء بشكل كبير بعد التقسيم ثم قمنا بتركيب هذا الحل في المرجل رقم 5 وكانت النتيجة فان المشكلة تم حلها بالكامل وقد عمل المرجل في المستوي المطلوب للضوضاء والاهتزازات. التوصية هي تنفيذ نفس حل التقسيم المراجل 3 و 4 عندما يكون المحطه جاهزاً لتثبيت التقسيم في مسارات الهواء قبل الشعلات سيتم التخلص من الجرعه الزائدة وسوف تعمل المراجل علي الاحمال العالية بدون ضوضاء واهتزازات.

CONTENTS:-

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List of Symbols /Abbreviations

A	m^2	Surface
Barg	Pascal	pressure gage
c_p	J/kg.K	Specific heat capacity at constant pressure level
k	m^2/s^2	Turbulent kinetic energy
k	mm	Coarseness
M	kg/kmol	Molar mass kmol kg
P	Pa	Static pressure
PR	Pa	Standing pressure
Qm	kg/s	Mass flow; $Qm = \rho \cdot Q$
Q	m^3/s	Volume flow; $Q = u \cdot A$
T	K	Temperature
Tu	-	Intensity of Turbulence
ε	m^2/s^3	Dissipation of turbulent kinetic Energy
λ	w/m.K	Thermal conductivity K m W□
ρ	kg/m^3	Density of fluid
η	$N.s/m^2$	Dynamic Viscosity

A	in surface of outlet boundary condition
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
E	in surface of inlet boundary condition
EPA	Environment Protection Authority
FI	Flow Induced
KNPS	Khartoum North Power Station
LTSH	Low Temperature Superheater
P	Porosity
PEL	Permissible Exposure Level
RDL	Register Draft Loss
OSHA	Occupational Safety & Health Administration
U	Ambience

CHAPTER ONE

INTRODUCTION

Combustion in boilers are considered to use the chemical energy in fuel to raise the energy content of water so that it can be used for heating ,manufacturing processes and power generation applications. Many fossil and non-fossil fuels are fired in boilers, but the most common types of fuel include nuclear, coal, oil, and natural gas. During the combustion process, oxygen reacts with carbon, hydrogen, and other elements in the fuel to produce a flame and hot combustion gases (Flue gases) these gases flow across the boiler tubes transferring heat to produce a superheated steam(Elie Tawil 2001).

The process of heat generation in boilers is a continuous as long as fuel and air are available .Boilers are manufactured in many different sizes and configurations depending on the characteristics of the fuel, the specified heating output, and the required emissions controls. Some boilers are only capable of producing hot water, while others are designed to produce steam, or superheated steam.

In last decades and before emissions regulations were issued, choosing the right boiler and combustion equipment for a particular application generally involved matching the process requirements with the boiler's output capacity. Proper sizing and selection required knowledge of the peak process requirements and an understanding of the load profile. This boiler selection philosophy emphasized energy conversion at the lowest possible cost. Reduced emphasis was placed on controlling emissions. Public concerns about air and water quality and enactment of federal, state, and local regulations have shifted this emphasis. The current design objective is to provide low-cost energy with an acceptable environmental impact. As discussed in an engineering manual published by American Boiler Manufacturers Association (ABMA), control of Nitrogen oxides (NOx), sulfur dioxide (SO2), particulate matter (PM) and carbon monoxide (CO) emissions is now a significant consideration in the overall boiler and combustion equipment design and selection process (Association 1998).

1.1 Problem statement:-

The maximum power output from any thermal power plant is top priority for engineers. The maximum power output means maximum loads which related to maximum fuel consumption and air flow control system (A/F ratio)

Vibration and noises resulted from the over dose of air –fuel ratio in boilers on the high load is the main consideration of this research project. The demand for electricity in the peak-loads generate an unacceptable noise and vibration.

1.2 Overview

The basic purpose of the boilers is to convert the chemical energy in fuel into thermal energy that can be used to generate steam or hot water. Inside the combustion chamber, two fundamental processes must occur to achieve this objective. First, the fuel must be mixed with sufficient oxygen to allow sustained combustion. The heated gases produced by the combustion process must then transfer the thermal energy to a fluid such as water or steam. Various components inside the boiler are required to promote efficient combustion and heat transfer. Their design depends on factors such as the type of fuel and the method selected to transfer thermal energy.

The boilers are manufactured in a wide range of sizes to burn coal, oil, natural gas and biomass as well as other fuels and fuel combinations. Most boilers are classified as either water tube or fire tube boilers. Fire tube boilers consist of a series of straight tubes that are housed inside a water-filled outer shell, the tubes are arranged so that hot combustion gases flow through the tubes. Water tube boilers are designed to circulate hot combustion gases around the outside of a large number of water-filled tubes, the tubes extend between an upper header, called a steam drum, and one or more lower headers or drums.

A burner is defined as a device or group of devices for the introduction of fuel and air into a furnace at the required velocities, turbulence, and concentration to maintain ignition and combustion of fuel within the furnace. Burners for gaseous fuels are less complex than those for liquid or solid fuels because mixing of gas and combustion air is relatively simple compared to atomizing liquid fuel or dispersing solid fuel particles.

The ability of a burner to mix combustion air with fuel is a measure of its performance. A good burner mixes well and liberates a maximum amount of heat from the fuel. The best burners are engineered to liberate the maximum amount of heat from the fuel and limit the amount of pollutants such as CO, NO_x, and PM that are released. Burners with these capabilities are now used routinely in boilers that must comply with mandated emission limitations. An effective way to minimize NO_x emissions is to use a low-NO_x burner (LNB). These burners employ various strategies for mixing the fuel with combustion air to reduce the formation of NO_x. Two techniques often used for this purpose include [1] introducing the fuel and air at different stages, and [2] recirculating flue gas with fresh combustion air. The LNBs that can be retrofitted to existing boilers have been developed and are currently being available. By implementing low-NO_x burners alone the NO_x level can be reduced by 40-50%, compared to traditional “high NO_x” burners (Flemming Skovgaard Nielsen 2012).

Boiler controls provide automatic regulation of burner and boiler performance to ensure safe and efficient operation. Operating and combustion controls regulate the rate of fuel input in response to a signal representing load change (demand), so that the average boiler output equals the load within some accepted tolerance. Water level and flame safety controls cut off fuel flow when unsafe conditions develop.

Water tube boilers are constructed of various types of steel panels made of tubes that have pressurized water flowing through them. The combustion fluctuation pressure occurs inside boiler furnace could be critical factor which generate noise and vibration. Flow induced vibration for boilers subjected to cross-flow have been a subject of investigation all over the world. In boilers, this flow cause internal forces which may generate vibrations and noise in the boiler during their regular operation. These vibrations can lead to tube thinning at support points and consequent leakage or damage to tubes and wear, damage to structural attachments as well as insulation cladding provided around the boiler. It could lead to forced shutdown of boiler to replace the damaged components or lost the boiler. Excessive noise can be a problem to plant operating personnel. Vibration and noise problems are occur when air or flue gases flow over the boiler(Observatory 2010).

Crucial problems of up normal noise and high vibration appeared during boiler operation on high loads of power station they are start gradually at high load and increase till they got unacceptable at full load and finally leads to shut down the boiler.

The vibrations of tube bundles / casing / panels are due to a scientific phenomenon known as flow induced (FI).

In heat exchangers, such as boilers for commercial use, acoustic resonant noise is occasionally generated in the ducts when gas is flowing laterally with respect to the axis of the tubes. The acoustic resonant noise generated from heat exchangers is usually caused by the resonance of acoustic modes inside the boiler and vortex shedding from the tube banks(Kunal R Bhatt 2014).

In boilers and ducts systems the source of noise can be from fans, improper ducts design, and abrupt transitions, the natural flame instability in any flare or furnace produces noise. In rare cases, though, it is loud enough to draw complaints from the neighbors and even vibrate equipment to destruction.

Noise formed by a flame only (due to burner instability). This type of noise usually is not very loud, but it increases as the pressure and flow of fuel and air increase.

1.3 Case Study:-

The Dissertation will take Khartoum North Power station (KNPS) as case study, it is a thermal power plant, built in three phases with total capacity of 380 MW and 6 units (Observatory 2010).

Phase 1**,** was built in 1984 including unit 1 and unit 2, capacity of each unit is 30 MW.

Phase 2، was built in 1994 including unit 3 and unit 4, capacity of each unit is 60 MW.

Phase 3، was built in 2011 including unit 5 and unit 6, capacity of each unit is 100 MW.

The traditional original burners “high NO_x” in phase 2 & 3 was installed on the boiler in 1994 , where these burners were replaced in 2008 by low NO_x burners to keep boiler emission from the chimney within international standard range of NO_x standard to protect the environment from pollution as Environment Protection Authority (EPA). The new burners is so different from the original manly the arrangement of primary and secondary air flow, oil burners and nozzles.

Therefore, after this modification all parameters of combustion emission are within the international standard, but there is a crucial problems appeared during boiler operation on high loads it got up normal noise and high vibration start gradually when the engine load exceed 40MW and increase till they got unacceptable so the unit can’t reach the maximum load at all. Continuous noise is normally defined as broadband noise of approximately constant level and spectrum to which the employee is exposed to for a period of 8 hours per day, 40 hours per week. A large number of industrial operations fit into this class of noise exposure. The Occupational Safety & Health Administration (OSHA) noise standard (Health 2004), 29 Code of Federal Regulations (CFR) 1990-95 (a) and (b) defines the Permissible Exposure Level

(PEL) as that noise dose that would result from a continuous 8 hour exposure to a sound level of 90 dB (OSHA 2008).

Hence, it is required to predict the occurrence of flow induced vibrations early-on and address the problem to avoid forced outages. Physical measurement of the vibrations in the boilers by measuring probes is difficult in the running boiler due to high temperature. So, there is a need to evaluate vibrations in affected regions theoretically. Computational Fluid Dynamics (CFD) tools have been found appropriate to perform the flow analysis. Owing to recent improvements in CFD, simulation and flow analysis for the gas is now practicable for industrial purposes.

1.4 The objective:-

From this study, accepted design modifications for burners and air supply ducts will be essential to increase the load of units till full load is possible and adjusting of operation parameters have been developed to operate boilers on the normal vibration and noise level to keep Khartoum North Power Station operating on acceptable load according to designed capacity.

Expected results and conclusions:-

1. At the end of this research the vibration and noise problems will be solved. And the results will be economically, environmentally, socially and efficient operation are acceptable.
2. To extend the life time of the boilers at the power station while generating the maximum power output.
3. To give guidance to consulting engineers to specify boilers that will work efficiently in Sudan climate.

CHAPTER TWO

LITERATURE REVIEW

2.1 LITERATURE REVIEW: (State of our knowledge):

In this chapter the previous work and researches will be cited .Previous techniques used to reduce the vibration and noise form boiler systems are briefly reviewed.

Tricks and Tools for Solving Abnormal Combustion Noise Problems effective Methods for solving combustion noise problems in boilers are reviewed. System modeling and diagnostic testing procedures are presented as well. Whenever I have been retained in recent years by a boiler manufacturer as a consultant to help solve a problem of combustion oscillation, I found that clients have not been very eager to deal with the complexities of feedback loops and modeling. What they really wanted was some magic solution. I am not Harry Potter, but I happen to know three tricks that may seem like magic. To start with, I will describe them and show that they are not magic at all (Peter K. Baade and Michael J. Tomarchio 2004).

.They all have perfectly logical explanations.

Trick No. 1 – Add Damper

Trick No. 2 – Stretch the Flame

Trick No. 3 – Drill a Holes

The conclusion are this case history shows that it is helpful to use a combination of simple modeling and diagnostic testing when confronting a combustion oscillation problem. Perfectionists might argue that this approach is merely a form of educated guessing. There may be some justification for that view, but we submit that educated guessing is a lot better than the random guessing inherent to the trial-and-error approach commonly used.

Our model has shown considerable promise for diagnosing oscillation problems in cases where it has been applied so far. We are aware that there are parts of the model that should be improved. In particular, estimates of damping due to the pressure drop across the heat exchanger and due to acoustic radiation from the surfaces of the boiler ought to be included.

The case is very limited and mainly not fully solve the problem due to working only for using tricks (three tricks) and these procedure is for education and showing only what happen when the trick will be applied. So all tricks used not give significant solution and they need more study for radiation heat transfer and pressure drop in site boiler. These

should be for the boilers with a maximum output of less than 500,000 Btu/hr not for large boilers.

The vibration analysis for the furnace structure was performed using FE model and fluctuating pressure. From the normal mode analysis results, the possibility of resonance was not expected considering fluctuating pressure. The overall vibration levels of the boiler are expected to be below 7 mm/sec in average value. From the vibration analysis results using CFD calculation and acoustic study, the furnace structure of super critical boiler is expected to have no vibration problem because there is no thermo-acoustic resonance and no the structure resonance (Hyuk-Min Kwon 2014).

The conclusion are the characteristics of fluctuating pressure in the furnace were investigated through CFD calculation. The fluctuation pressure in the furnace has tonal frequencies of 2.4 Hz and 7.0 Hz which are corresponding to 1st and 2nd acoustic modes. The maximum amplitude of the fluctuating pressure is 400 Pa and the amplitude level keeps constant and does not increase with respect to time. This confirms indirectly that there is no high noise level during operation.

The vibration analysis for the furnace structure was performed using FE model and fluctuating pressure. From the normal mode analysis results, the possibility of resonance was not expected considering fluctuating pressure. The overall vibration levels of the boiler are expected to be below 7 mm/sec in average value. From the vibration analysis results using CFD calculation and acoustic study, the furnace structure of super critical boiler is expected to have no vibration problem because there is no thermo-acoustic resonance and no the structure resonance.

The paper is study the case of analysis the noise and vibration using CFD and FEM but the result is found nothing to be done and the level of noise and vibration are within the stander level so no change in the design or operation parameters will be follow to improve the noise or vibration.

Analysis of flow induced vibration Phenomenon has been studied for horizontal Low Temperature Superheater (LTSH) tube bundles in utility boilers at full load operation. Flow analysis has been performed using commercial software FLUENT and the results have been used to predict the occurrence of vortex shedding and acoustic resonance phenomenon for LTSH. From the analysis, it has been observed that LTSH receives varying flow distribution along the depth of boiler. The phenomenon for vortex shedding and acoustic resonance has been observed in the boiler. The trend of calculated vibration amplitude at reference elevations has been found to be similar to the site measured values. The sources of error and their effect on the model in deviation of conditions from the actual ones have been discussed. The model can be used to predict vortex shedding and acoustic resonance phenomenon at different operating loads by changing the boundary conditions. Thus an optimum operating load range could be predicted for the boiler to operate avoiding vortex shedding and acoustic resonance phenomenon (Aditya Kumar Pandey* 2012).

The conclusion are the flow induced vibration phenomenon has been studied for horizontal Low Temperature Superheater (LTSH) tube bundles in utility boilers at full load operation. Flow analysis has been performed using commercial software FLUENT and the results have been used to predict the occurrence of vortex shedding and acoustic resonance phenomenon for LTSH. From the analysis, it has been observed that LTSH receives varying flow distribution along the depth of boiler. The phenomenon for vortex shedding and acoustic resonance has been observed in the boiler. The trend of calculated vibration amplitude at reference elevations has been found to be similar to the site measured values. The sources of error and their effect on the model in deviation of conditions from the actual ones have been discussed. The model can be used to predict vortex shedding and acoustic resonance phenomenon at different operating loads by changing the boundary conditions. Thus an optimum operating load range could be predicted for the boiler to operate avoiding vortex shedding and acoustic resonance phenomenon.

The paper is concentrated on superheats only not on all boilers and they are many other parameters effecting noise and vibration like type of burners, ducts design, furnace pressure, flam length, type of fuel, gas combustion quality etc…

All flames make noise the natural flame instability in any flare or furnace produces noise. In rare cases, the noise can be loud enough to damage equipment, cause nuisance shutdowns or bother the neighbors. Simple hardware changes can eliminate the problem, but sometimes finding the right fix takes time, and larger ones make more. Most people can’t hear the noise from a pocket lighter, but they know when their gas water heater or gas-fired central heat burner starts. And any industrial-size furnace makes enough noise that you can tell if it is on without looking. Usually, combustion noise can be ignored -- it seldom causes problems. In rare cases, though, it is loud enough to draw complaints from the neighbors and even vibrate equipment to destruction. This article will consider five cases like that.

The conclusion are eliminating combustion pulsation and excessive noise is possible through changes in burner operation (reduce or increase airflow, change steam flow, etc.), but often, some sort of hardware change is required. There is some hope from acoustic analysis of the resonating chamber, but this is presently very difficult and typically too expensive to use in the equipment design phase. More practical approaches include changing the location or velocity of fuel injection(Dan Banks 2011).

Another involves changing the location direction of combustion airflow, steam flow or waste flow. And in some cases, steps must be taken to change the resonant frequency of the furnace/stack assembly. These changes are typically accomplished in an experimental manner. Sometimes, observation of the flame body will give a clue as to the best approach.

The paper is presenting many solutions without study and diagnoses of the source of the problem and for furnace chamber (resonating chamber) they mentioned it is very difficult and too expensive because it used in the equipment design phase, so the result is not satisfied to solve the problem and not fully analyses the solutions.

How to Solve Abnormal Combustion Noise Problems This article discusses abnormal combustion noises in boilers, burners and heating systems. An experimental method is described to provide insight into the causes of such noises (Peter K. Baade 2004) .

Several techniques are presented for the reduction or elimination of abnormal combustion noises.

During the development of a new boiler, burner or heating system it is always possible that a prototype will emit an unacceptably loud noise that is clearly abnormal. Although the occurrence might be infrequent, its very presence necessitates elimination before the product can go to market. Since the noise is so abnormal, it is tempting to think that a solution will be found quickly by making some small design changes. If one is very lucky, this cut-and-try approach may indeed work. Most likely, however, it will be frustratingly slow and may not succeed at all.

The solution is mention for the boiler that during manufacturing process and can make change of design by check it on prototype and this it more easy then work on solving problem in operation boiler after more than 10 year in operation

To examine the spectrum requires an analyzer, which also provides a means for recording wave shapes and is an indispensable tool for solving abnormal combustion noise problems. Any attempt to solve such problems without such a tool is like shooting blindfolded. Still, while an analyzer is essential, it will not answer all questions by itself.

A good insight into the mechanism that causes the pressure oscillations is also required.

Mapping of the pressure field in the combustion chamber can be a very useful tool for diagnosing some abnormal combustion noise problems in actual heating equipment. For either of the test methods, the probe tube must be designed to prevent overdriving the pressure transducer.

Under actual operating conditions, the resonance frequency will be considerably higher because the speed of sound increases with temperature. Still, such measurements can be useful for diagnosing a problem of abnormal combustion noise because they provide more insight into how the unit behaves. By extrapolation, a rough estimate of the resonance frequency of the hot system can be obtained, which is sufficient to determine whether the oscillations do indeed occur at the resonance frequency of the combustion chamber.

For some burner designs, this is best accomplished by increasing the velocity through the burner. Increasing damping by a sufficient amount will always work, although smaller increases will have little effect on the noise.

To demonstrate this, slide the damping sleeve up very slowly while listening to the noise. Until the critical position is reached where the oscillations are stopped, there is very little reduction of the total noise. Beyond that position, the reduction is quite sudden.

While any substantial changes in air/fuel ratio may not be acceptable as a permanent solution, it is useful to explore this in a real unit if permitted by the burner design. Doing so will make it quite clear that the flame drives the oscillations even though practical solutions can often be found without changing the flame(Peter K. Baade 2004).

They only concentrated on increasing air velocity through the burners and increasing the damping by a sufficient amount, and this can be used by changing in operation parameters on it done by Khartoum North Power Station without change in noise and

vibration level so the change in operation parameters can effecting on environmental aspect and the level of combustion quality.

CASE STUDIES IN BOILER VIBRATIONS AND BFP CAVITATION In this paper two case studies are presented, which are relevant to boiler operating and design engineers. One is a vibration problems experienced in CFBC boilers and other is about a repeated BFP failure in a power plant. (K.K.Parthiban 2013)

The boiler was inspected during operation. Plant engineers had stiffened the duct casing, thinking that the duct stiffeners are inadequate. Even after the additional stiffening of the casing, the casing was cracking. On shut down inspection, it became clear that the cause for vibration was the acoustics created by the air leak from air side to gas side. Heavy air leak could be seen from the lifting holes of APH blocks.

KNPS Phase II boiler inspection was carried many time during shut down but no gas leak was observed.

BOILER VIBRATION Earlier experience on the British designs of gas cooled reactors Indicated that flow induced vibration of boiler tubing could be a serious problem, leading to tube fretting during operation. As a result of this experience there was some concern during the construction period. In order to ensure that a high standard of information could be obtained during commissioning, several boiler pods at each station were instrumented with strain gauges and/or accelerometers. During the fuelled engineering runs in 1982-3, the vibration responses of the Instrumented boilers were monitored as a part of a programme of measurement covering the complete gas circuit, including the reactors internal structures, the gas circulators, the boilers, and the fuel and plug unit assemblies. Measurements were taken over a range of gas densities, flows up to design levels, and at temperatures up to 282 Deg C. Nitrogen Injection also took place to correct the acoustic conditions to design levels. This programme of measurement was supplemented by further monitoring during the power raising period, when higher gas temperatures up to 556 ^{o} C were achieved. The effects of single boiler insolation were also measured.

The main finding of the tests were that changes in vibration levels with flow and gas conditions were modest. During the engineering runs the maximum estimated stress levels were generally in the range 2-4 MN/m with peak values of up to 6 MN/m. These compare with design predictions of 4.5 MN/m and a maximum allowable design value of 7.4 MN/m. Sliding wear effects were also of relatively low amplitude.

During the power raising tests, estimated stress levels reached a maximum of 4.3 MN/m in the radial direction, and 2.3 MN/m in the axial direction, both below the design limit of 7.4 MN/m. Estimates of sliding wear were in the range 0.08 - 0.15 mm /30 days, well below the limit for 30 year design life of 1.23 mm /30 days. Further monitoring of boiler vibration has continued through the period of operation, and although the instrumentation failure rates are now increasing (as was expected) no significant ageing effects have come to light.

As a result of the excellent performance Indicated by these tests, an application to increase the reactor coolant mass flow to 105% of design level for normal operation (as an aid to higher output) was approved by the Safety Authorities at the end of 1986 (MATHEWS 1986).

They the solve the problem during design and commissioning stage

<u>Flow simulations solve WHRSG vibration issues</u> Petrobras engineers prepared a hybrid mesh of around 15.5-million nodes for the unit's flue-gas domain (outside the tube bundles), including the gas-inlet duct and the diverter valve . Engineers also used a finite-volume method to solve transient Navier-Stokes equations with the aid of a commercial code. Considering Petrobras engineers' hypothesis that vibrations in the steam generator are caused by vortex shedding from the inlet duct structure, the team proposed two new geometries for the duct. The first uses an elbow for the "T", keeping the sectioned curve of the duct, while the second replaces parts both after the diverter valve and before the steam generator with curves tangent to ground level. These proposed changes sought to avoid the backward-facing step vortex-shedding phenomenon by smoothing the flow. Both were simulated at 100% rated capacity for comparison with the original geometry Substitution of the "T" with an elbow eliminated only one of the recirculation zones. The one in the horizontal section remained and reduced flue-gas flow area while increasing velocity intensity. These results indicated greater instability and high-pressure regions where sudden changes in flow direction occurred.

The configuration with curves provided a more organized flow and avoided sudden changes in flow direction. A greater number of recirculation zones were eliminated and the velocity intensity reduced, lowering flow instability at the WHRSG's entrance

Pressure-oscillation magnitude dropped by up to 6.5 times in the case of the elbow duct and by up to 50 times with the curve duct (Barbara L. da Silva 2016).

This paper they solve the problem but by replace the duct by complete new design

<u>NOISE REDUCTION METHODS FOR WALL GAS BOILERS</u> Noise emissions reduction methods for wall gas boilers are here investigated. An intensimetric and vibration measurement campaign has been carried out in order to individuate the suitable noise reduction solutions. Numerical simulations have been led by means of a volume finite code to verify the compatibility between such solutions and the boiler thermofluidodynamic properties. A 3.5dB average acoustic power reduction and a 5.0dB average vibration level reduction have been obtained. A measurement campaign has allowed to verify that the proposed methods do not affect the boiler thermofluidodynamic performances (Duranti 2003).

Two noise insulation solutions have been proposed solid-borne and airborne measurement results have shown that the highest noise reductions are obtained by means of polyurethane-lead multilayer panels (airborne noise reduction) and polyurethane and flexoid gaskets (solid-borne noise reduction).

This paper solved the problem, because they used type of insulation to protect the surrounding environment without solve the root cause of the problem, but in our case is not only to eliminate the noise and vibration but to improve the boiler capability to work up to maximum load with standard level of noise and vibration

2.2 Basic Burner Design

Combustion requires three components – Fuel, Oxygen (air) and Ignition. In its simplest form a burner can be considered as an arrangement to combine these three components in a controlled manner.

The burner consists of an air register for controlling the flow of combustion air, and fuel injectors for controlling the flow of gaseous or liquid fuels. The burner has to meet these requirements for flow metering, whilst producing the necessary aerodynamic patterns for flame shape and stability in conjunction with the spatial distribution of finely atomized fuel oil, to meet the specified combustion performance (Li 2009).

Within the design of the burner there are a fuel oil gun, gas guns, an air register and an igniter. The basic requirements of each part can be briefly described as follows:-

2.1.1 Fuel Oil Guns

Liquid fuel must be atomized into very small droplets to permit rapid intermixing of air and fuel. Atomization is achieved by the use of steam atomizers. The determined fuel rate must be passed at the specified input pressure (COMBUSTION 2009).

2.1.2 Combustion Air Register

The design of the air register in which the burner is fitted is of considerable importance in obtaining efficient combustion. In addition to overall combustion efficiency, the air register must produce a stable, self-propagating flame, capable of withstanding varying burner outputs and air pressures. Any alteration in burner output must always be accompanied by a corresponding adjustment of forced or induced air pressure in the register to provide just sufficient air to allow complete combustion of the fuel.

With steam driven fans, the air pressure is adjusted by altering the speed of the fan. Whereas with motor fans, which generally run at constant speed, the air pressure is adjusted by opening or closing dampers or shutters in the air duct, either on the suction or discharge side of the fan. With automatic control systems, the fan speed, damper or shutter is opened or closed by an automatic controller working in conjunction with the fuel flow controller.

Again, the requirements of the air register are interrelated, but for descriptive purposes are identified as follows:-

a) Calibration

The amount of air determined as that necessary for the complete combustion of the designated fuel rate, must be passed at the design pressure differential.

b) Mixing Energy

The register draught loss (R.D.L.) determines the velocity and energy of the combustion air. This must be sufficient to provide the necessary air/fuel mixing energy to control flame shape to a suitable specific application as shown in figure (2-1) the maximum efficiency zone(Yasuo 2015).

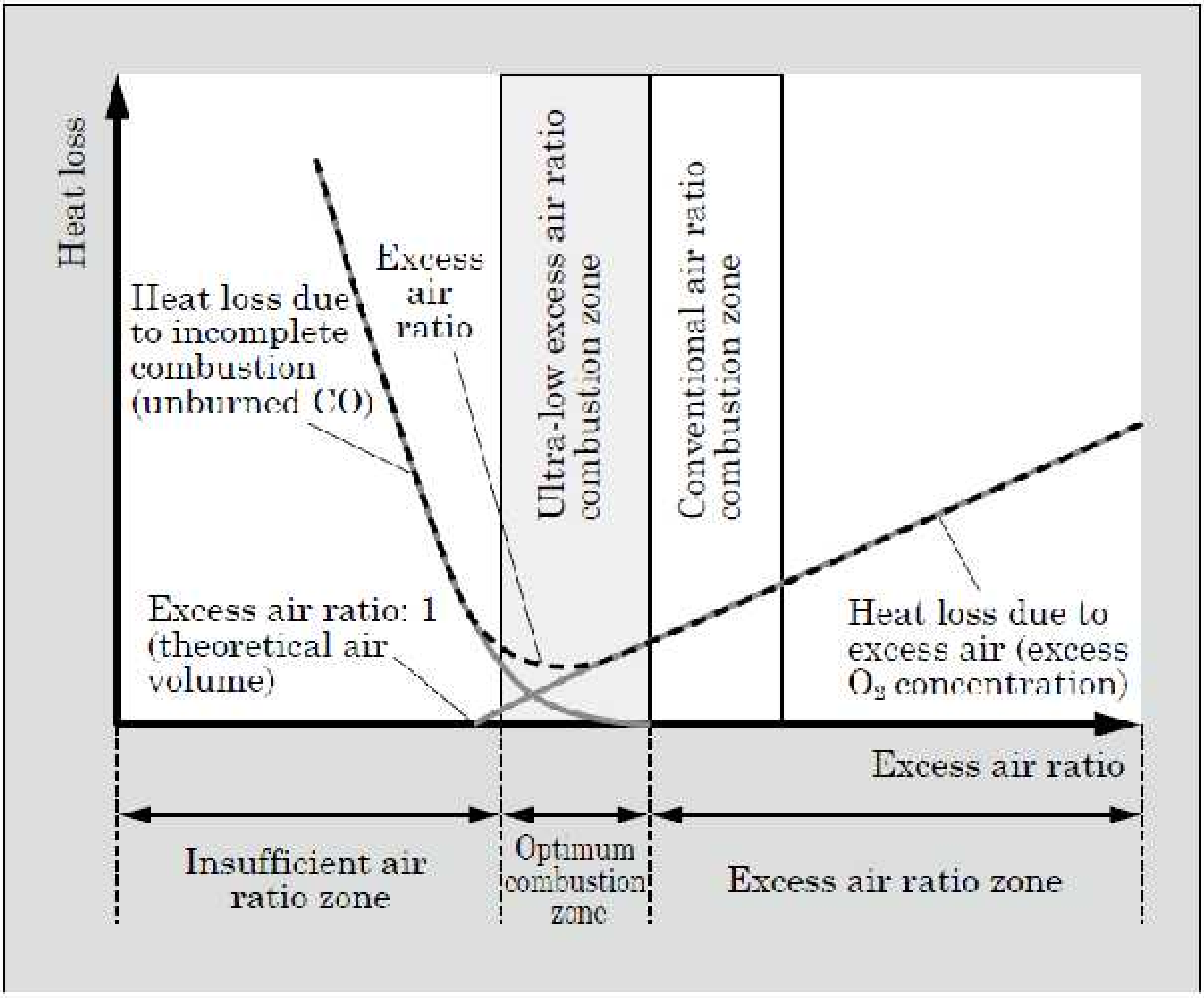

Figure (2-1): Boiler Efficiency

C) Flame Stability

The fuel and combustion air pressures necessary to provide the mixing energy for acceptable combustion, results in air/fuel mixture velocities in excess of the flame propagation speed.

This situation left on its own would produce unstable flames, as it would be many burner nozzle diameters downstream of the burner before the mixture velocity and the flame propagation speed reach equilibrium.

To overcome this unacceptable condition, a proportion of the combustion air, identified as primary air, is highly swirled. This sets up an adverse axial pressure gradient resulting in a reverse flow along the axis and the setting up of an internal recirculation zone just downstream of the fuel gun, see figure (1-2)

The re-circulated burning gases provide a continuous source of re-ignition and thereby produce a stable flame.

The proportion of primary air and the strength of swirl must be sufficient to generate the required stabilizing recirculation and also to ensure that the re-circulated gases are within flammable limited(COMBUSTION 2009).

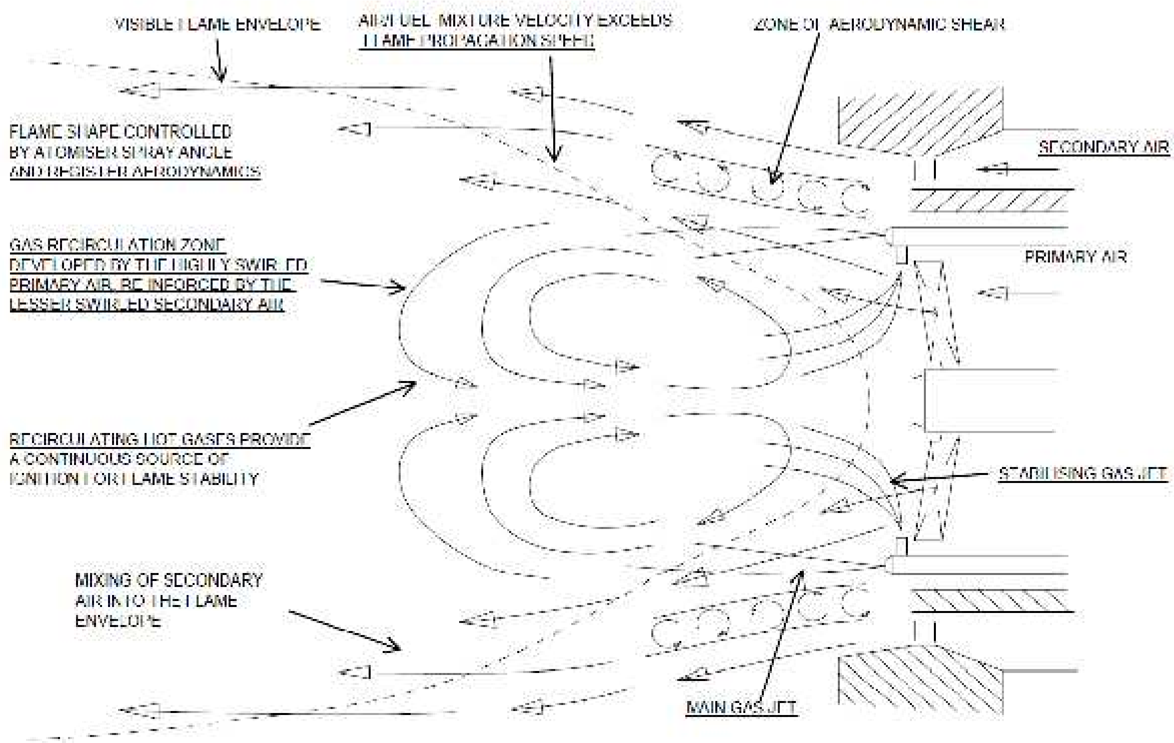

Figure (2-2): Schematic of flame stabilizing and mixing patterns gas spud firing

d) Flame Shape

The primary air therefore provides the major influence on flame stability. The remaining combustion air, secondary air, in addition to reinforcing the aerodynamically controlled stability pattern can be used in the control of the flame shape. The secondary air can be swirled or un-swirled depending on the required flame pattern.

It is unlikely that the secondary air swirl is ever required to be as strongly swirled as the primary air.

Whilst it is possible to effect some change of flame shape by adjusting the fuel spray or combustion air pattern individually. Major shape change requires adjustment of both in order to achieve optimum results be correct matching of fuel to air.

2.1.3 Air staging

The principle of air staging means applying just enough air to make the combustion stable but not enough to allow the nitrogen to be oxidised to NO and NO2. The NOx formation is governed by local furnace parameters such as gas-temperature and composition, and in low-NOx burner designs the combustion air is controlled so that a staged mixing of fuel and air takes place. The result is a long flame where zones with simultaneous high temperature and high air-fuel ratio, are avoided.

By implementing low-NOx burners alone the NOx level can be reduced by 40-50%, compared to traditional "high NOx" coal burners (Flemming Skovgaard Nielsen 2012).

The combustion system is composed by five air flows. The three co-axial burner air outlets are:

1. Primary air (PA: The primary air and conveying air for the pulverized fuel)
2. Secondary air (SA)
3. Tertiary air (TA)
4. Over burner air (OBA: The air nozzles above each burner)
5. Over fire air (OFA: The air nozzles above the burner zone)

2.3 Computational Fluid Dynamics (CFD):

The combustion process inside a modern water tube boiler is a complex phenomenon, consisting of numerous chemical reactions all of which play an important role in boiler performance. Traditionally these boilers were designed using lumped thermal models of the combustion reactions to determine fluid composition and properties. However, these methods required empirical correlation factors that may not have been appropriate for all applications(Thompson 0000).

CFD technology enables engineers to model the combustion process and related physics of various fossil- and biomass-fired water tube boilers and resolve any design and operating problems before manufacture and commissioning. When doing these computations different physical models are implemented in the code to simulate the process.

Physics in the CFD model include: tracking of the fuel particles, evaporation and depolarization of these particles, surface combustion on the fuel particles, the combustion process in the gas, radiation heat transfer and pollution formation.

A high level of geometric detail is included in the model to capture certain key results. The geometries considered in detail are the fuel spreaders, the combustion air system and furnace. The tube banks of the various heat exchanger sections are also included.

The results from the CFD analysis show the temperature contours, flow patterns, and gas composition throughout the boiler. The image on the right shows combustion gas temperature contours displayed on a plane through the Centre of the boiler model. These more precise calculations and data enable us to keep improving our boiler designs which are Industry benchmarks.

The full three-dimensional Navier-Stokes equations are employed with five species transport equations (Raja Saripalli 2005). The problem is modeled with the following general assumptions:

1. The flow is steady and incompressible.
2. Variable fluid properties.
3. Turbulent flow.
4. Instantaneous combustion with the chemical reaction much faster than the turbulence time scale.
5. The steam temperature is assumed as the tube wall temperature.

2.4 Governing Equations

The conservation equations for mass, momentum and energy in general form are shown below.

$$\frac{\partial \rho}{\partial t} + \nabla . \rho \vec{V} = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

$$\frac{\partial}{\partial t} \rho\vec{V} + \nabla . \rho \overline{VV} = -\nabla p + \nabla . \bar{\bar{\tau}} + \rho\vec{g} + \vec{F} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla\cdot(\vec{V}(\rho E + p)) = \nabla\cdot\left(k_{eff}\nabla T - \sum_j h_j J_j + (\bar{\bar{\tau}}_{eff}\cdot V)\right) + S_h \quad \text{.....(3)}$$

$\bar{\bar{\tau}}$, the stress tensor is given by

$$\bar{\bar{\tau}} = \mu\left[(\nabla\vec{V} + \nabla\vec{V}^{T}) - \frac{2}{3}\nabla\cdot\vec{V}\,I\right] \quad \text{…………………(4)}$$

Where I is the unit tensor.

The CFD program solves the Navier–Stokes equations with different kε-models or an implemented kω-model for the unsteady turbulent viscous and incompressible flow field (K. Schroder 1999). The object of this project is to find a model, which describes the gas flow vibration excitation and enables an accurate computation of critical velocities in ducts, burners and furnace of the boiler

2.5 Draught (see also Furnace Draught under Fans)

Draught is defined as current of air/gas, especially the one intruding into an enclosed space. In boiler draught signifies the pressure difference below that of the atmosphere. Flow of air and gas inside boiler is also generally termed as boiler draught(RAYAPROLU 2013).

Early boilers operated under induced/natural draught, which relied entirely on the stack without the aid of fans, to provide air and gas flow through the boiler, purely by the ρ difference of air between the bottom and top of the stack.

Modern boilers with so many tube banks inside and HP SA/TA can scarcely operate on the meagre stack effect and need fans for creating adequate draught.

Balanced and FD are the two modes of boiler operation depending on whether the gas pressure in furnace is neutral (furnace static pressure = atmospheric pressure) or positive. Both types of operations are depicted in figure (2-3) below which shows the profile of air and gas pressures across a typical boiler.

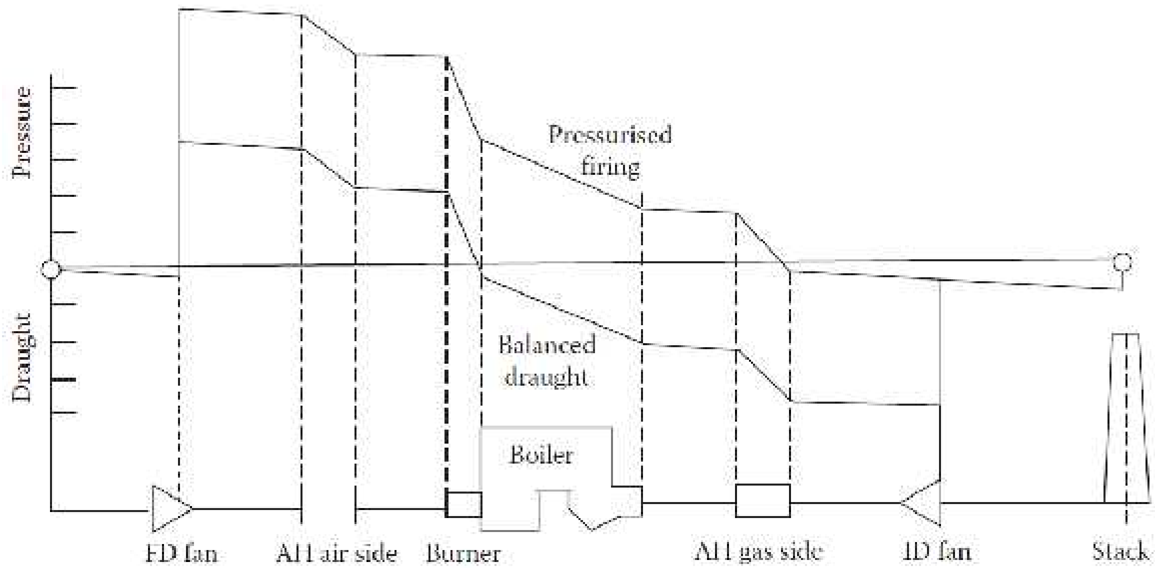

Figure (2-3): Draught profiles in forced and balanced draught firing

2.6 Draught Plant

This is an all-inclusive term to describe all parts in the air and gas flow circuit outside the main heat transfer surfaces. Draught plant usually consists of

a. Equipments like fans, dust collection equipment and so on

b. Fabricated items such as flues and ducts, expansion joints, dampers and bypass stack

Equipments in (a) are not a parts of study items in this research (b) are elaborated here under the headings of

a. Flues and ducts

b. Expansion joints or compensators

    1. Metallic expansion joints

    2. Non-metallic/cloth/fabric joints

c. Dampers

    1. Isolation dampers

        a. Multi-flap or louver dampers

        b. Guillotine dampers

    2. Control dampers

    3. Diverter dampers

    4. Weather/stack dampers

d. Bypass stack

2.7 Flues and Ducts

Ducts that carry flue gases and combustion air are termed, respectively, as flues and ducts in a boiler.

Construction wise there is no difference but by convention ducts carry air and flues carry gas. They are purely fabricated items employing sheet steel of 4 and 5 mm for ducts and 5 and 6 mm for flues. It is not usually economical to fabricate them in the boiler shops. They are normally subcontracted or even site fabricated.

Compact layout and optimum sizing of the flues and ducts is essential to contain the overall costs of boiler. In most cases, their size is decided by the equipments they are connected to. There are prescribed velocity limits for optimal sizing of various ducts to avoid excessive pressure loss, noise, erosion and vibration. Adequate stiffening and supporting is also essential besides proper sizing.

It is usual to internally brace ducts >2 m. Square or rectangular ducts are most common, but it is the round ducts which are most economical and are used extensively for diameters up to 1.5 m as the permissible air/gas velocities can be higher and stiffening minimum.

CS is most common constructional material but when the temperatures are >450°C, low AS or SS are used. At times brick or insulation lining on the inside is adopted. The former is needed for abrasive gases such as those from coal while the latter is employed for non-abrasive flue gases from oil/gas firing. In extreme high temperatures, like the downstream of duct burners, lining with C fiber mattresses is employed if the gases are clean.

Layout engineering of flues and ducts is very important as it contribute in a big way for the pressure losses and the fan power. Generous sizing, no doubt, reduces losses but increases the auxiliary power cost and vice versa. A good layout is a fine balancing act.

A typical air and gas duct diagram of boiler is shown in figure (2-4) below along with places where gas analysis is usually taken.

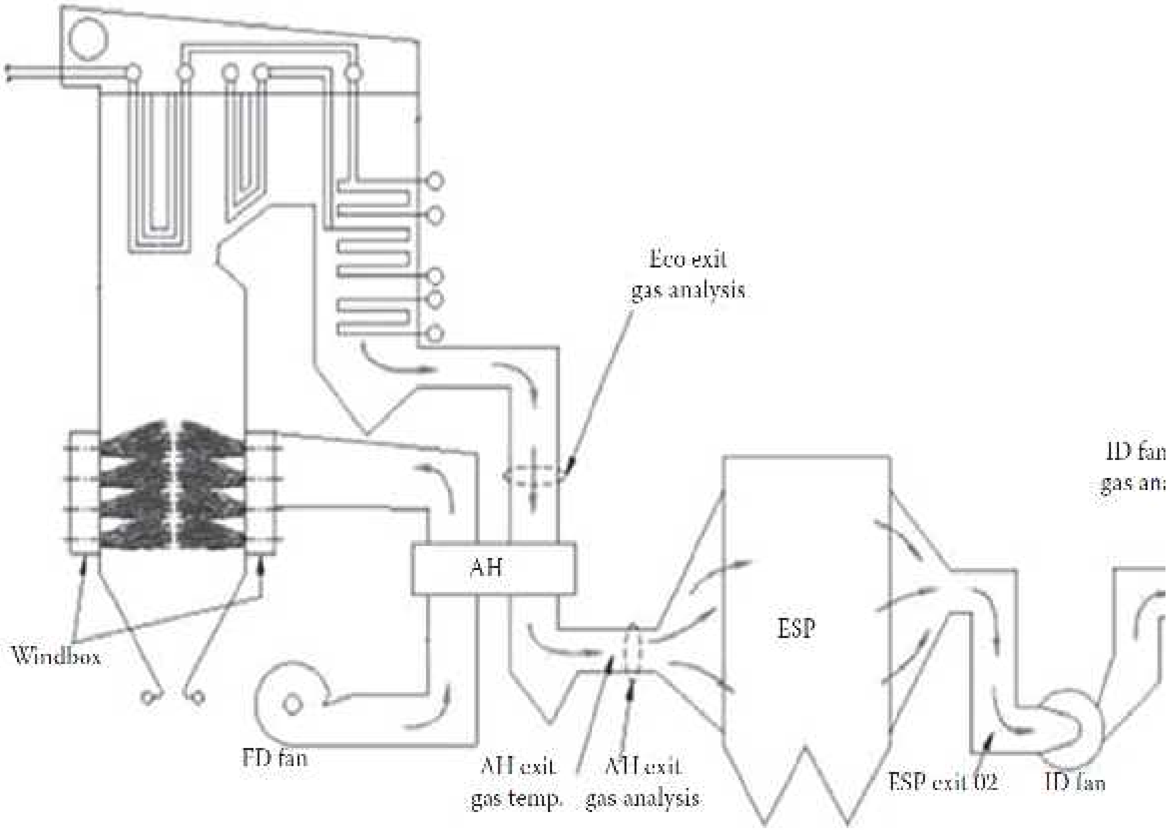

Figure (2-4): Flues and ducts in a typical boiler.

CHAPTER THREE

MATHEMATICAL AND ANSYS MODELLING

3.1 Introduction

As the combustion process takes place in the furnace, oxygen in the combustion air combines chemically with the carbon and hydrogen in the fuel to produce heat. The amount of air that contains enough oxygen to combine with all the combustible matter in the fuel is called the theoretical air.

It is improbable for every molecule of fuel that enters the furnace to combine chemically with oxygen. For this reason, it is necessary to provide more air than the theoretical requirement. For most boilers, it is customary to provide 5 to 20 percent more air that the theoretical requirement to ensure complete combustion. This additional air is called "excess air". A boiler firing at 1.2 times the theoretical air requirement would be said to be firing at 20 percent excess air. If insufficient oxygen is introduced into the furnace, incomplete combustion of fuel will occur. This wastes fuel, causes air pollution, and results in hazardous conditions in the boiler. The unburned fuel may ignite in the boiler and result in secondary combustion, causing a dangerous explosion.

Providing too much combustion air reduces the explosion danger, but also reduces efficiency. The largest energy loss in a boiler is the heat that escapes as hot flue gas. Increasing the excess air increases this energy loss. High excess air can also result in unstable burner conditions due to the lean fuel/air mixture.

In practice, a large number of items that affect boiler efficiency are related to excess air. The proper value of excess air is a function of boiler load, fuel quantity, and air leakage through idle burners, steam temperature, flame stability, and energy losses.

3.1.1 Basic and Ideal Combustion

An ideal fuel burning system would have the following characteristics:

- No excess oxygen or unburned combustibles in the end products of combustion
- A low rate of auxiliary ignition-energy input to initiate the combustion process
- An economic reaction rate between fuel and oxygen compatible with acceptable nitrogen and sulfur oxide formation

- An effective method of handling and disposing of the solid impurities introduced with the fuel
- Uniform distribution of the product weight and temperature in relation to the parallel circuits of heat absorbing surface
- A wide and stable firing range, fast response to changes in firing rate, and high equipment availability with low maintenance

Efficient combustion of any fuel depends on its chemical and physical characteristics, and how well it is mixed with combustion air. Three important factors - time, temperature, and turbulence - control the completeness of combustion and influence the design of boiler equipment and operating practices.

- TIME- Normally, combustion reactions are so rapid that the time to complete them seems instantaneous. A good example is the combustion of gasoline in an internal combustion engine. However, natural gas or a droplet of oil will travel several meters in the furnace and require a finite period of time between the start of ignition and the completion of burning.
- TEMPERATURE- If a mixture of air and fuel is heated gradually, a temperature will be reached at which outside heat is no longer required and rapid combustion occurs. This temperature is referred to as the ignition temperature and is defined as the temperature at which more heat is generated by the combustion process than is lost to the surrounding atmosphere. At this point, combustion becomes self-sustaining. Below this point, the fuel/air mixture will not burn freely and continuously unless external heat is supplied.
- TURBULENCE- If the fuel and air are mixed in swirling paths, instead of each flowing in streamlined paths, combustion will be greatly improved because the mixing of fuel and air is more complete. The proper amount of air for a given amount of fuel means nothing if the two are not mixed.

3.2 **Divided Flow Low-emission (DFL) Modified Burner Geometry at KNPS Boilers**

It has to be recognized, of course, that there are four basic contributory causes of the total NOx emission:

♦ Burner Design

♦ Operating Condition

♦ Furnace Design

♦ Fuel Properties

Therefore it is not possible for the burner design to be capable of overcoming all the contributory causes of NOx. Burner manufacturers do, of course, represent a major design input towards the reduction of NOx emissions. Boiler and furnace designers also have an important contribution to make in terms of furnace dimensions to increase residence time, number and location of burners to promote internal flue gas recirculation and the availability of external flue gas recirculation, and reduction in combustion air preheat (by compromising boiler efficiency). In multi-burner applications, consideration to be given to the possibility of splitting the furnace into fuel weak and rich zones. Existing plant may require down rating to achieve the necessary increase of residence times. Pressure parts may require modification to accommodate the optimum number of burners or to change burner throat size for FGR etc. Plant users and fuel suppliers must consider fuels appropriate for the duty and emission limits and not just cost. Given applications need serious analysis to weigh up the effectiveness of combustion modification, 'efficiency and fuel costs' and exhaust gas treatment and effluent disposal.

Hamworthy have developed a burner geometry, which in conjunction with specially designed and located fuel oil atomizers and gas nozzles, achieves reductions of both thermal and fuel NOx emissions (COMBUSTION 2009).

The application of these procedures does have an effect on flame shape when compared to the previous standard non low NOx burner. Flame length is virtually unchanged but an increase in flame diameter is observed and must be taken into account when considering specific furnace flame fit.

3.3 Case study

Target of the investigation was the complete air supply system of boiler 3 and 5 in Khartoum North Power station. To identify Noise and vibration Sources the power station operates over 24 hours, seven days a week run continuously throughout the week .

The boiler operate by a force draft fans (FD) at the input. The air forced to the boiler through the air duct to the burners of the boiler and will be the main source of the phenomenon of flow induced (FI) and will generate noise and vibration for the boilers on high load.

The air supply system overview can be seen from Figure (3-1) and (3-2) for boiler 3 and 5 respectively. The whole geometry was assembled from sub geometry parts. Main goal was to find solution for bad air distribution to the burners in certain load cases.

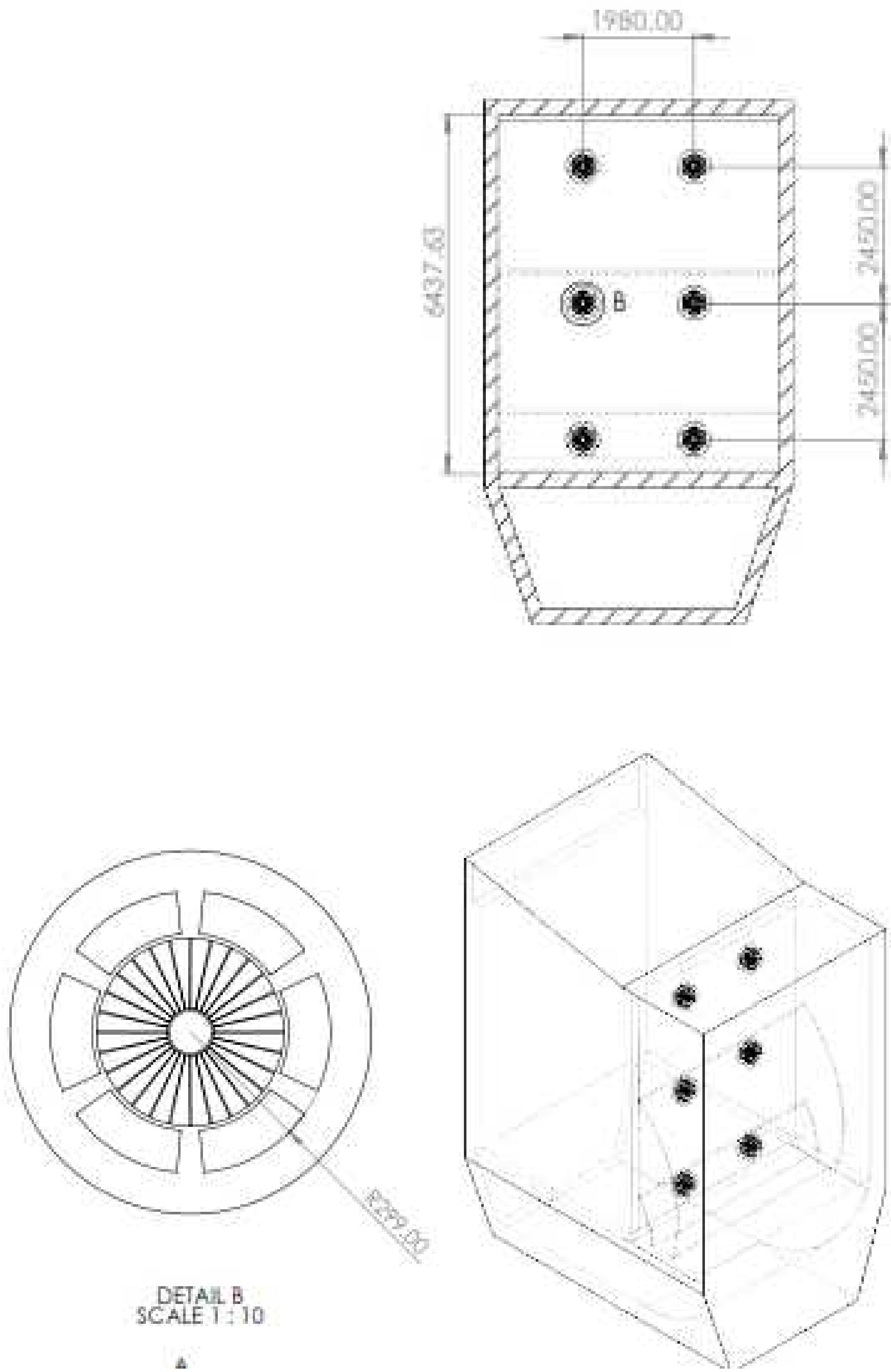

Figure (3-1): Boiler 3 duct geometry with designation of the sex burner inlets

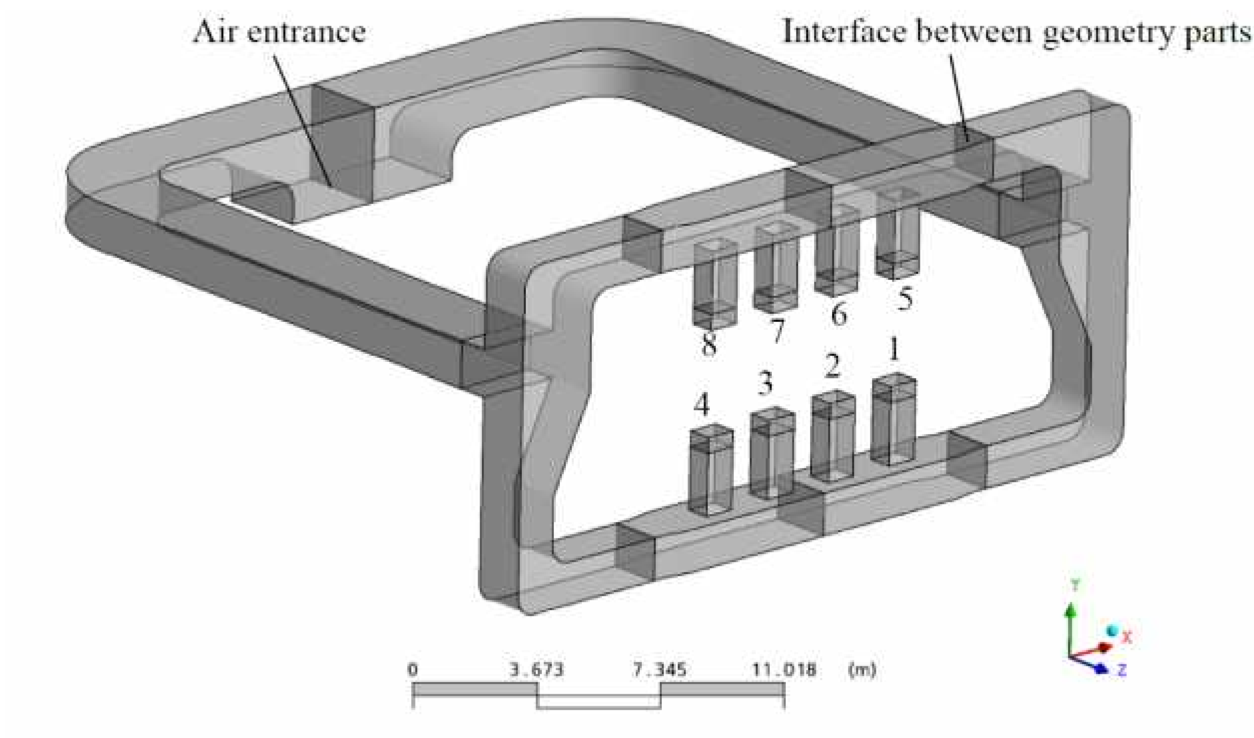

Figure (3-2): Boiler 5 duct geometry with designation of the eight burner inlets

The analysis of flow conditions was performed using the numerical flow field calculation with CFD - program system ANSYS CFX ANSYS. The flow was turbulent with the physical characteristics of air, assumed as an ideal gas. In each case, steady flow conditions were implemented in the simulations.

CFD is one of the ways to virtually design and run the simulation experiment without the need to physically build the model. The cost of model building and repeat the process until the desired result is very huge. This process can be done by CFD modelling using commercial software and it is very much cheaper compare to physical model building. CFD has been successful in carried out the simulation on many engineering problem (Baukal 2001), such as gas turbine, internal combustion engine, industrial furnace, flameless combustor and other engineering applications

3.4 GOVERNING EQUATIONS

CFD calculation and mathematical processes are governed by fluid flow governing equations. The equations are series of fluid properties which are mass conservation (continuity equation), density, temperature, species, mass fraction, enthalpy, turbulent kinetic energy (k) and turbulent dissipation rate (ε) (M.M.Noor July 2013), the transport equations are:

Mass (the continuity equation)

$$\frac{\partial \rho}{\partial t} + \nabla . \rho U = 0 \qquad \text{……………………(5)}$$

Momentum

$$\frac{\partial \rho U}{\partial t} + \nabla . \rho U U = \nabla p + \nabla . t + \rho \qquad \text{……………………………..(6)}$$

Enthalpy

$$\frac{\partial \rho h}{\partial t} + \nabla . \rho U = \nabla . \lambda_e - \nabla . q_{rad} + \nabla . \sum_l \rho \square_l (T) D_e \nabla m_l \qquad \text{……..(7)}$$

Temperature

$$\rho C_p \frac{\partial T}{\partial t} = \nabla . \lambda_e \nabla T - \nabla . \sum_l \rho \square_l \; T \; D_e \nabla m_l - \rho \sum_l \frac{D m_l}{D t} \square_l (T) \qquad \text{…….(8)}$$

Species mass friction

$$\frac{\partial \rho m_l}{\partial t} + \nabla . \rho U m_l = \nabla . D_e \rho \nabla m_l - R_l \qquad \text{……..……………….(9)}$$

The most common turbulent model is k-ε model and (B.E. 1972, BI 1974), this model was practical for many flows and relatively simple to implement and easy to converge. The equation for turbulent kinetic energy (k) is and turbulent dissipation rate (ε) are below.

$$\frac{\partial}{\partial t} \rho k + \frac{\partial}{\partial x_i} \rho k u_i = \frac{\partial}{\partial x_j} (\mu + \frac{\mu_t}{\sigma_k}) \frac{\partial k}{\partial x_j} + P_k + P_b - \rho \epsilon - Y_M + S_k \qquad \text{……..(10)}$$

$$\frac{\partial}{\partial t} \rho \epsilon + \frac{\partial}{\partial x_i} \rho \epsilon u_i = \frac{\partial}{\partial x_j} (\mu + \frac{\mu_t}{\sigma_\epsilon}) \frac{\partial \epsilon}{\partial x_j} + C_{1\epsilon} \frac{\epsilon}{k} (P_k + C_{3\epsilon} P_b) - \rho C_{2\epsilon} \frac{\epsilon^2}{k} + S_\epsilon \qquad \text{….(11)}$$

Where turbulent viscosity, $\mu_t = \rho C_\mu \frac{k^2}{\epsilon}$, production of k, $P_k = -\overline{\rho u_i' u_j'} \frac{\partial u_j}{\partial x_i}$ effect buoyancy $P_b = \beta g_i \frac{\mu_t}{Pr_t} \frac{\partial T}{\partial x_i}$ and $\beta = -\frac{1}{\rho} (\frac{\partial \rho}{\partial T})_p$, in the effect of buoyancy, g_i is the In the effect of buoyancy is the component of the gravitational vector in the $it\square$ direction and P_r is turbulent Prandtl number. P_r is 0.85 for the standard and realizable $k - \varepsilon$ model. Other model constants are $C_{1\epsilon}, C_{2\epsilon}, C_{3\epsilon}, C_\mu, \sigma_\epsilon \; and \; \sigma_k$. The common fluid flow problem can be solved in one dimension, two dimensions or three dimensions with parabolic, elliptic or hyperbolic equations.

3.5 3D mathematical simulation

Today, the issue of firing system design for the boilers is especially acute for retrofit or green field construction of power units in order to comply with a number of requirements for environmental protection, slagging, combustion stability, as well as boiler safety, reliability and efficiency(Bartashuk E. G. and D.S. 2011).

The tool of 3D mathematical simulation of firing processes is becoming more common allowing for engineering solutions. Currently, the approval of the accepted solutions with the Client making use of 3D simulation analysis is not only normal, but also required for design works.

Conceptually, the procedure of 3D mathematical simulation of firing processes in the boiler for selection of the retrofit/upgrade option consists of the following stages:

1. Acquisition of the initial data required for computer simulation of firing processes in the existing boiler, including the following:
    - Existing boiler geometry.
    - Fuel
    - Boiler design characteristics
    - Boiler testing results
    - Current performance data.
2. Development of the existing model of boiler firing system and simulation of the operating mode.
3. Optimization of design and operating parameters of the main burners and nozzles.
4. Report on the optimal retrofit option with description and analysis of all design parameters.

Key models used for 3D simulation of the firing processes making use of Fluent are as follows:

1. K-ε turbulence model accounting for the influence of flow turbulence on the particle movement.
2. P-1 radiation heat transfer model.
3. A fuel burns out in stages.

The arrangement and general view of the burner is shown in Figures (3-3), (3-4) and (3-5) below (COMBUSTION 2009)

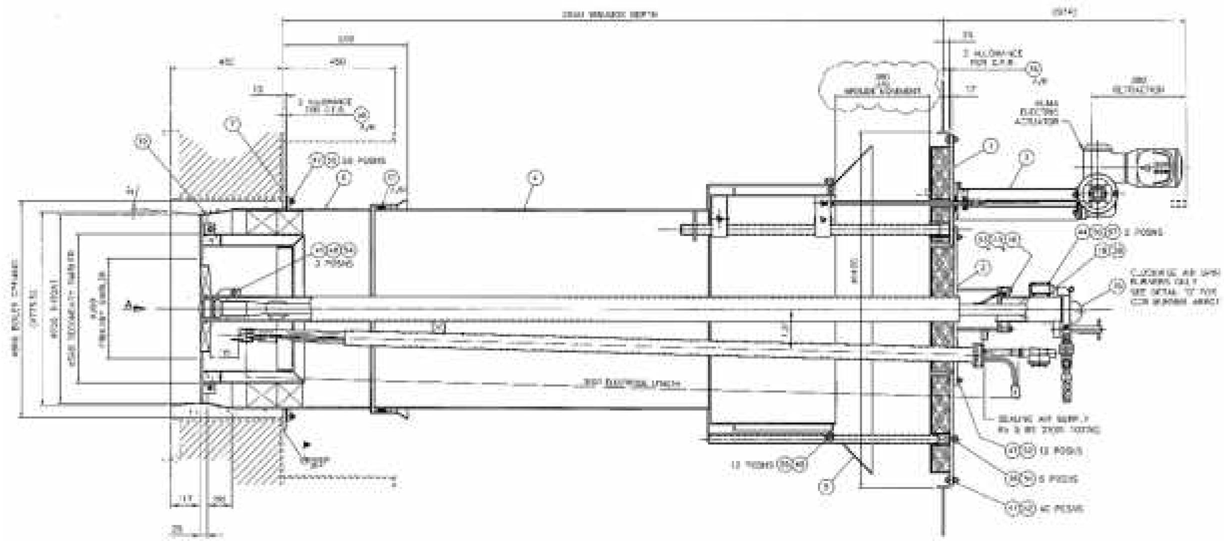

Figure (3-3): Composite Section through Burner

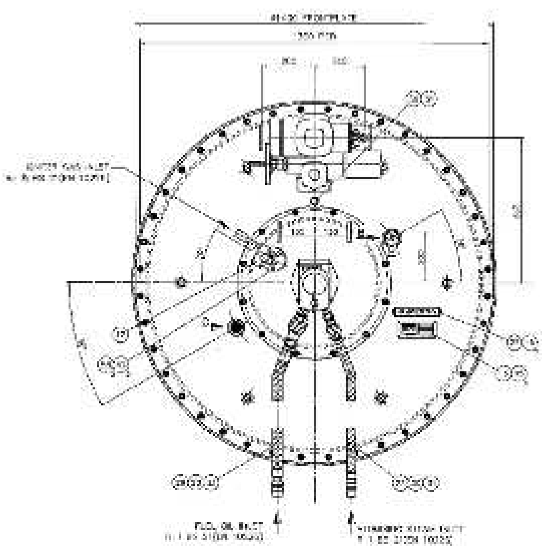

Figure (3-4): Front View

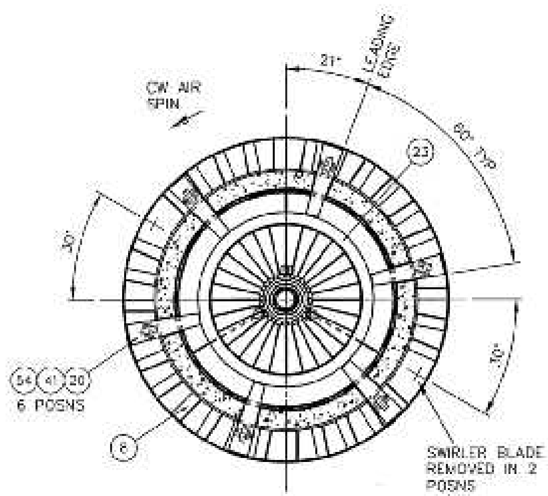

Figure (3-5): View on arrow ‘A’

3.6 Burner Design Data and boundary conditions:-

Boiler 5 Data

Geometry and boundary conditions

The calculated flow field extends from the outlet of the air preheater to the burner´s wind boxes (without flaps). The pressure drop of the burner is represented by a respective porosity. Since the porosity affect the velocity profile, a channel length of L= 2000 mm was chosen for the burner outlets for clarity / sensing the flow conditions at the burner inlet.

The air mass flow rate is Q_m = 66.9 kg / s. Velocity profile was chosen as a constant distribution in the inlet cross-section. The resistance coefficient of porosity was determined by the conditions:

Q_m,B = 66.9 / 8 = 8.3625 kg/s

ΔpB = 21 mbar

PFR = 25 mbar(ü)

PU = 1 bar

TL = 235 °C.

The static pressure in the outlet section is PA = 2500 Pa (pressure in the combustion chamber). As turbulence model, the k-ε-Model was used. The walls were defined as rough with k = 0.3 mm. Generally apply to the calculations the following conditions:

Fluid: Air (compressible, assumed as an ideal Gas)

Properties Air:

$\eta = 2.609 \cdot 10^{-5}$ N·s/m^2

$\lambda = 2.61 \cdot 10^{-2}$ W/(m·K)

Cp = 1026 J/(kg·K)

M = 28.96 kg/kmol

Boundary conditions:

Q_m = 66.9 kg/s

T_E = 235 °C

P_A = 2500 Pa(ü)

P_U = 1 bar(a)

ΔpP = 2100 Pa

Wall-rest conditions:

Adiabatic; coarse with k = 0.3 mm

Turbulence model: k-ε - Model with Tu_E = 5 %

Boiler 3 Data

Boiler	240 TPH, forced draft
Number of Boilers/Burners	Two boilers with six burners
Combustion Chamber Length	8800 mm
Combustion Chamber Height	12300 mm
Combustion Chamber Width	5800 mm

Operating Data

Thermal Input to Boiler	183.2 MW per 6 burners
Max register draft loss	51.5 mbarg
Combustion Air flow	61.60 Kg/s at BMCR
Combustion Air Temp	287°C
Excess Air	5% nominal at MCR
Oil Firing Rate	497.7kg/h to 2490kg/h per burner

Burner Data

Number of burners	12
Burner size	DFL755
Heat Input per burner	30.5 MW
Turndown	5:1
Atomiser	4HL 85/3
Burner RDL (HFO firing)	17.85 mbar

The **burner** differential pressure also sometimes called register draft loss (**RDL**)

Fuel Oil (HFO)

Type	HFO
Atomizing Viscosity	15 cSt
Oil Gross CV	44.15 MJ/kg
Stoichiometric Air	10.58 Nm3/kg
Oil flow / burner (MCR)	2490 kg/h

Turndown Oil Flow	498 kg/h
MCR Oil Pressure	10.66 barg
Turndown Oil Pressure	2.68 barg

Atomising Steam

Pressure	8.3 barg
Consumption per burner	146.4 kg/h at turndown
Oil and steam flow	0.178917 Kg/s to 0.732333 Kg/s

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Flow condition of the existing supply system

Boiler 5 as below in figure (4-1) and (4-2) show the simulated streamlines in the air duct. Striking is a largely parallel flow in the lower plenum and a vortex / swirl in the upper plenum, caused by flow of the air into the manifold (tees). Because expansion factor Inflow / Distribution surface is 2:27, the air flow breaks away. The constriction in the direction of lower distribution channel ensures stable flow condition. The constriction in the direction of the upper manifold duct, in conjunction with the deflection leads to the formation of swirl inside the flow pattern.

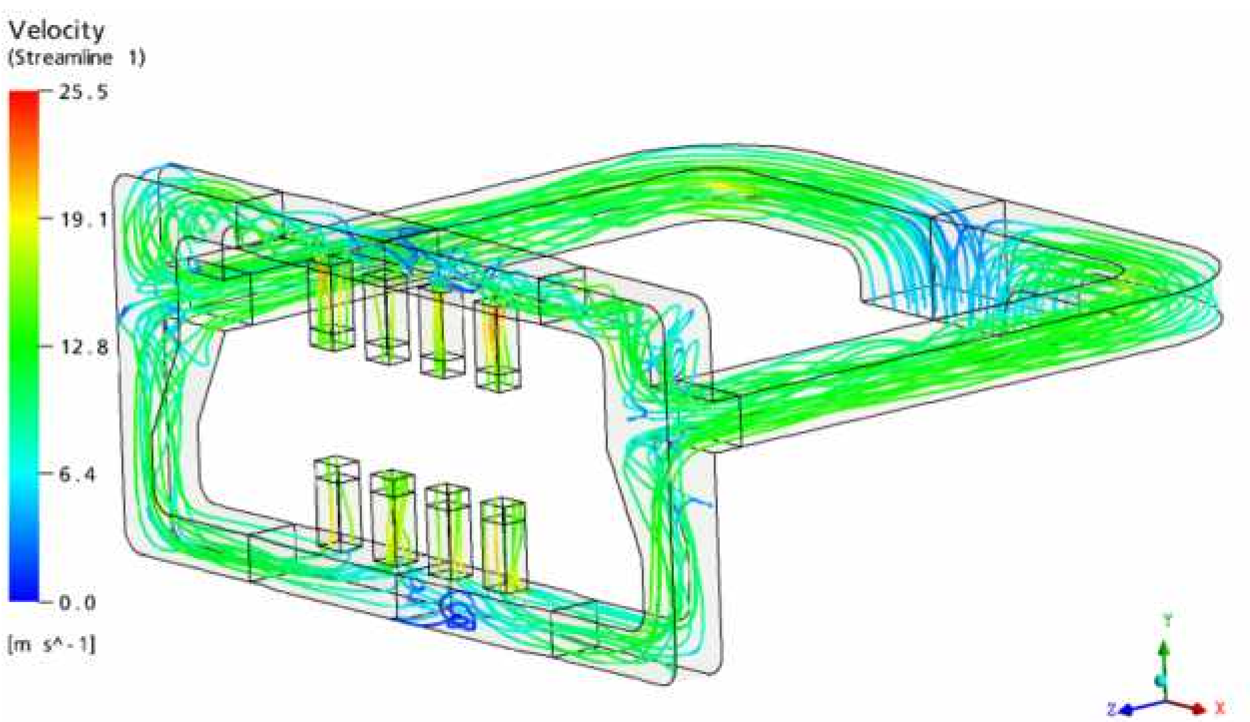

Figure (4-1): Calculated Stream lines

Figure (4-2): Detail Calculated Stream lines

The calculated mass flow deviation between the individual burner outlets is relatively small. The air supply is symmetrical, so that a symmetrical distribution is expected. The calculated mass flow rate of each burner is also equal to two symmetrical. In the lower branch, however, represents a periodic mass flow fluctuation in the burner outlets. This clearly shows the calculation without porosity.

For boiler 3 as mentioned below in figure (4-3) showing the stream lines of air flow at wind-box and burners out let before partition and figure (4-4) and (4-5) showing after partition and the mass flow is relatively same in all burners after partition of wind-box at the outlet of the burners and no different of mass flow at the all level of burners.

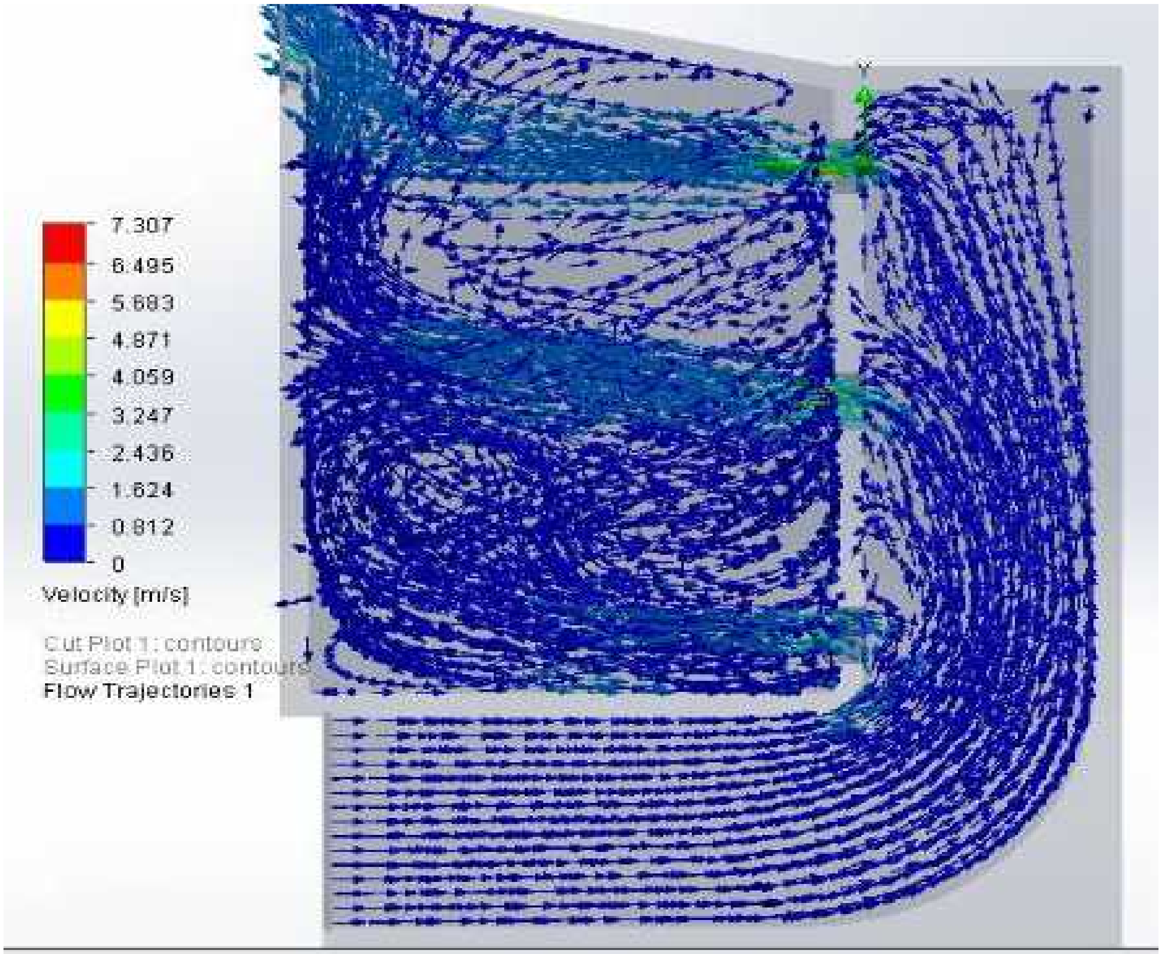

Figure (4-3): Unit 2 Boiler 3 air flow before partition

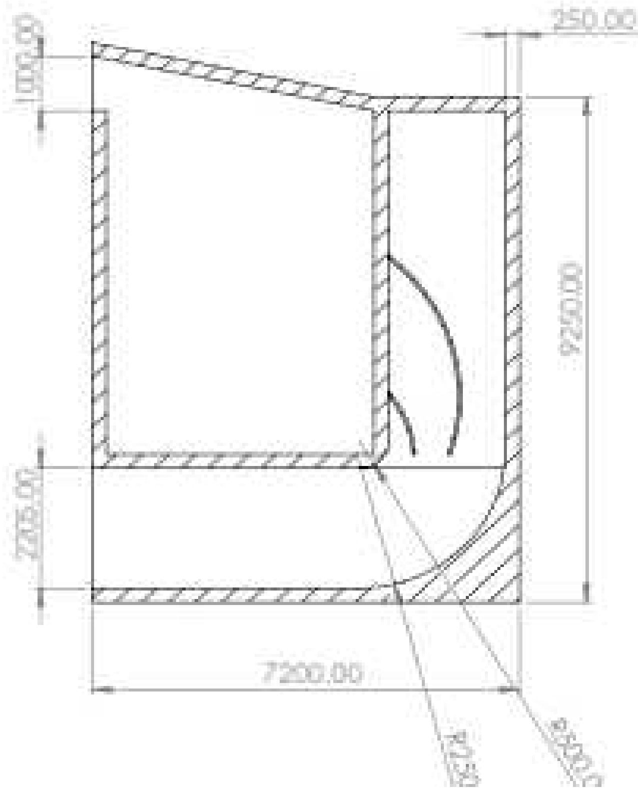

Fig. (4-4): Boiler 3 after partition

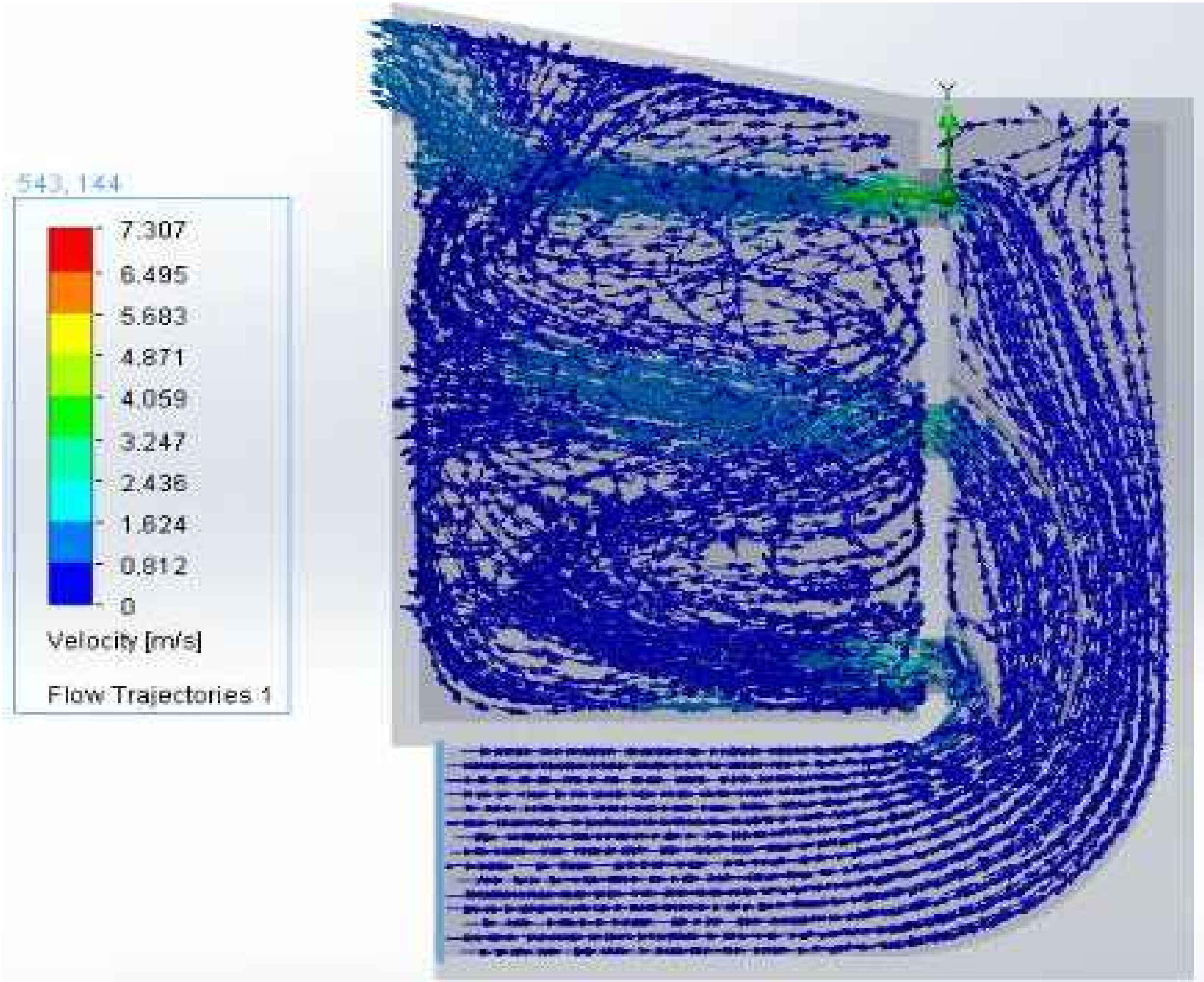

Figure (4-5): Unit 2 Boiler 3 air flow after partition

4.2 Flow conditions in the tee

As before mentioned, the air flow breaks away inside the tee. Reason is the larger cross-section inside the tee compared to the duct between the air preheater and the tee.
It has been carried out several calculations, how the flow pattern can be upgraded. But there was no solution without judge modification at air channel´s side walls. The remaining swirl inside the upper header is not disturbing the entrance of the air towards the burner inlets too much. So it was decided, to use the tee as it is and avoid extended modifications in this area.

4.3 Flow conditions at burner inlets

The sharp deflection at the burner inlet of the original geometry causes a velocity distribution in the flow towards the burners. In this section, the geometry for the improvement were examined. Best result is shown in Figure (4-6) Version 3: inlet funnel 30 °, R = 300 mm upstream + guiding vane L = 300 mm, height 300 mm Calculated velocity distributions show Figure (4-7) and Figure (4-8).

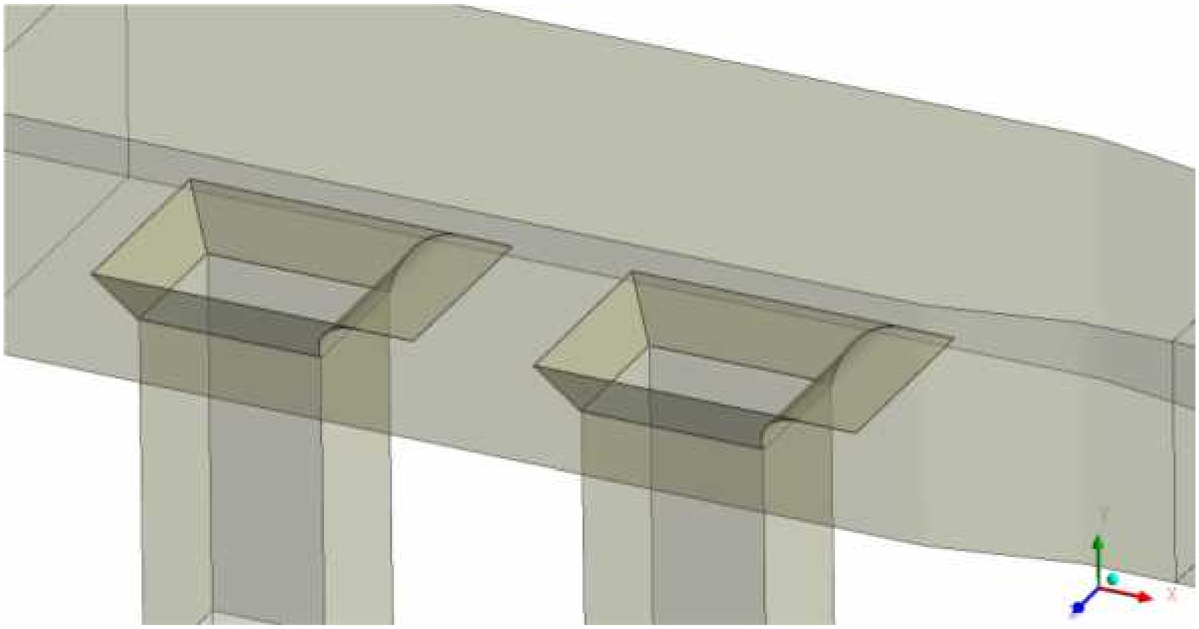

Figure (4-6): Geometry Version 3

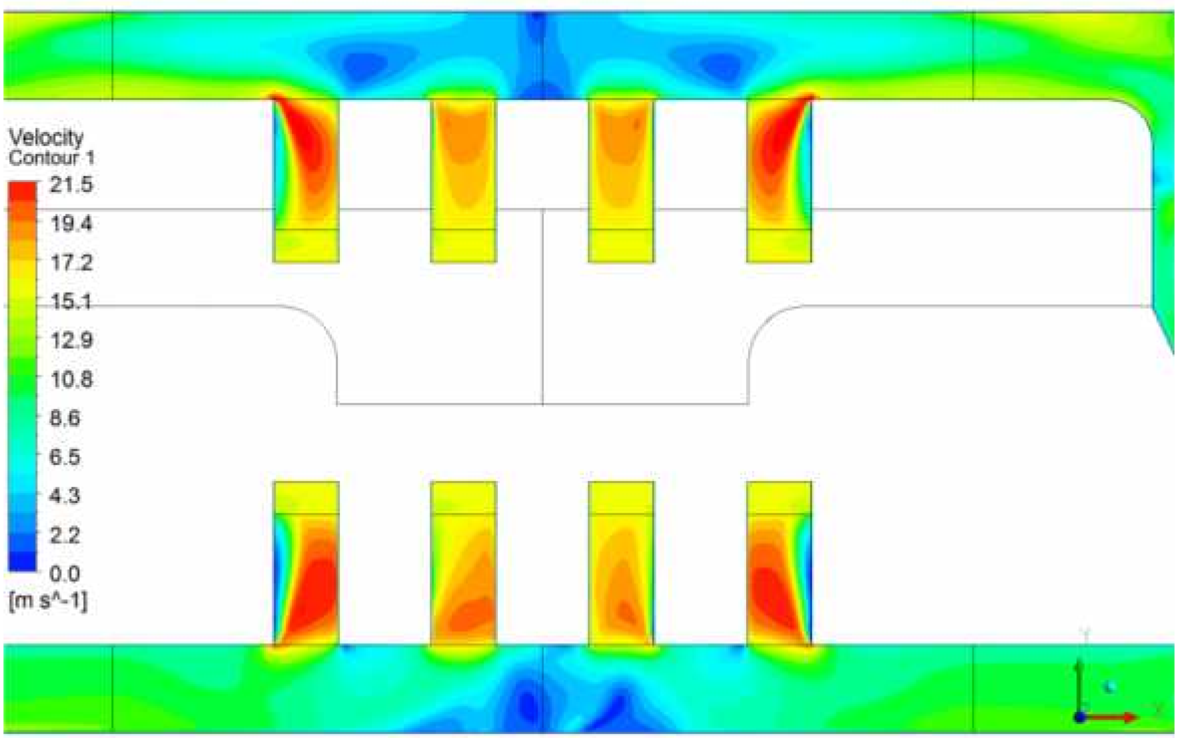

Figure (4-7): Calculated velocity distribution in the center plane in burner´s inlets (original geometry)

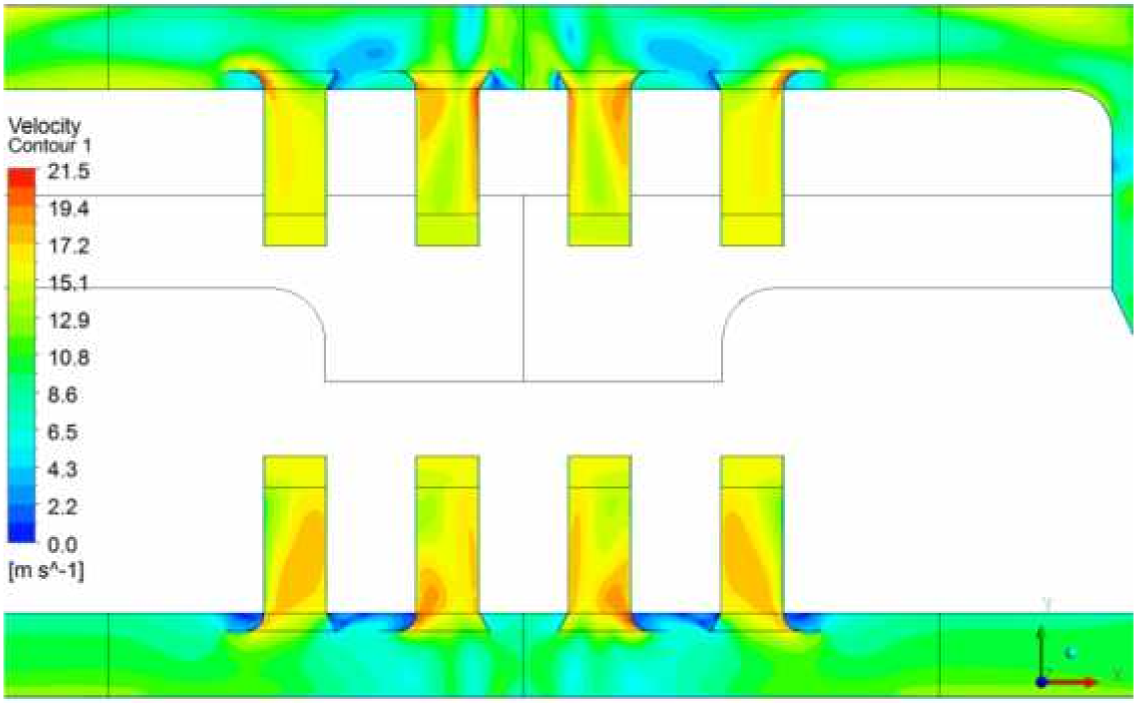

Figure (4-8): Calculated velocity distribution in the center plane in burner´s inlets (geometry option)

The calculated mass flow deviation between the individual burner outlets is relatively small at the same level. The air supply is symmetrical, so that a symmetrical distribution is expected. The calculated mass flow rate of each burner is also equal to two symmetrical. In the lower branch, however, represents a periodic mass flow fluctuation in the burner outlets. This clearly shows the calculation without porosity.

4.4 Investigation of partitions

To partition the upper duct from the lower by metal sheet, the connection of the upper and lower distribution channel seems to favor a slight periodic variation in flow rate into the burner outlets. The mass exchange between the two lateral air intakes are not locked, see Figure (4-9).

Having an upper and lower partition wall of the mass transfer is inhibited. The mass flow fluctuations in the burner outlets are no longer calculated. There are, indeed, the simulation according to the expected steady-state flow conditions, see Figure (4-10).

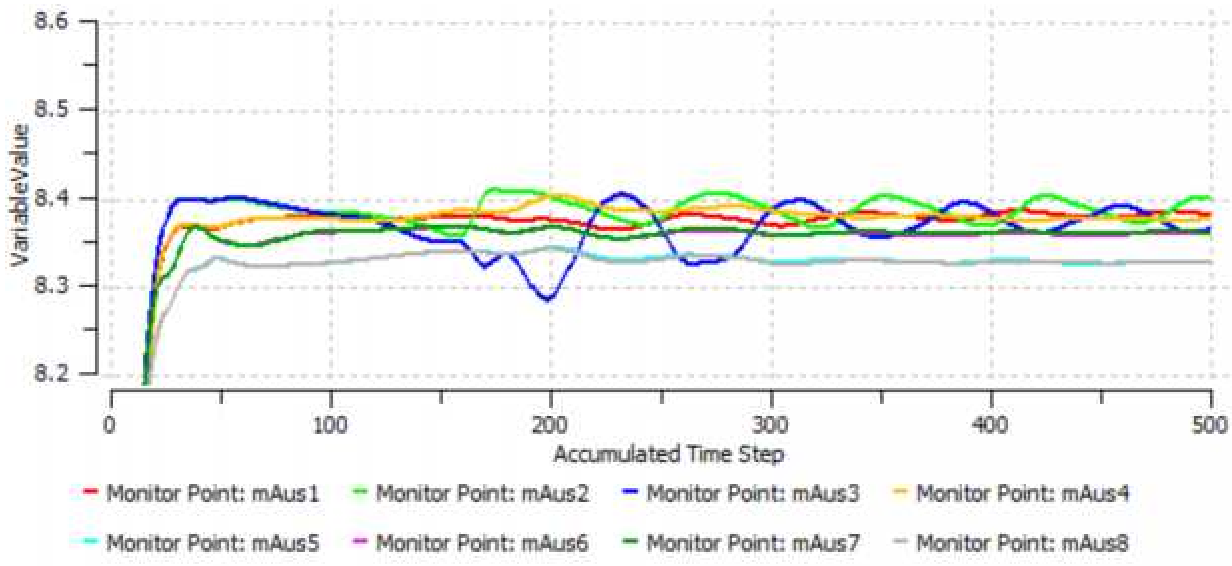

Figure (4-9): calculated mass flow distribution [kg / s] in the eight outlet cross-sections during the iterative solution for the original geometry without partition

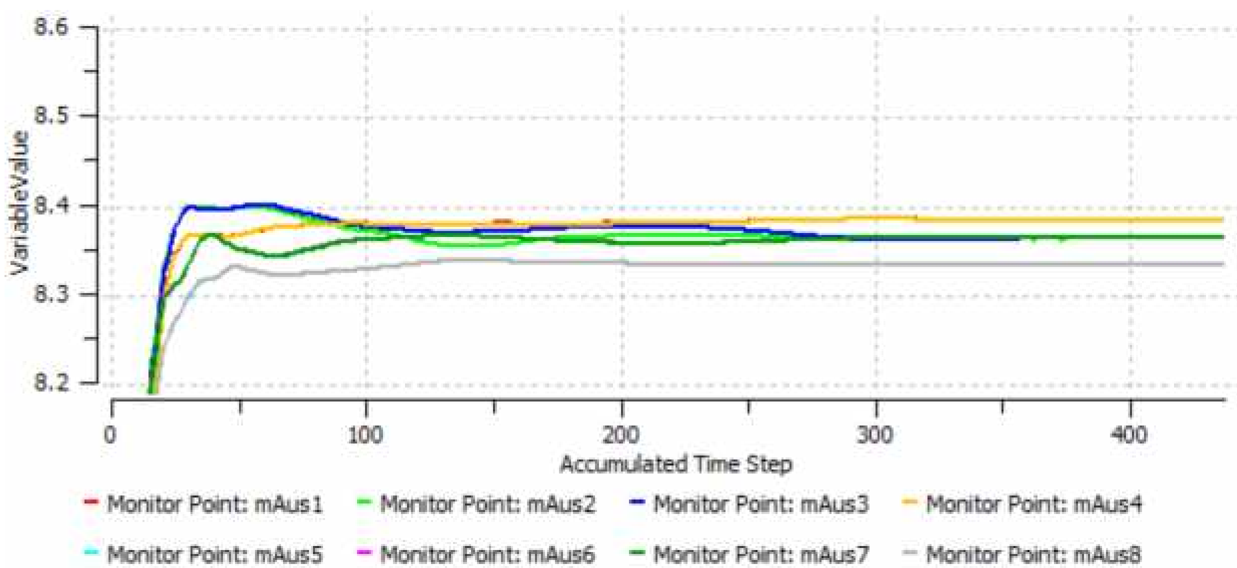

Figure (4-10): Calculated mass flow distribution [kg / s] in the eight outlet cross-sections during the iterative solution for the original geometry with a lower and upper dividing wall (partition**)**

4.5 Switch on/off of a burner by increase load of unit

During the operation of the boiler it is planned to switch off individual burners for cleaning purposes. In the simulation, the total mass flow remained constant despite the burner is turned off. Thus, the increase of combustion air mass flow rate of the operating burners at 114%.

The mass flow distribution for the initial geometry without burner 6 is shown in Figure (4-11), (4-12) and (4-13), as an example. It is independent which burner is switched off, the air distribution remains stable and equal.

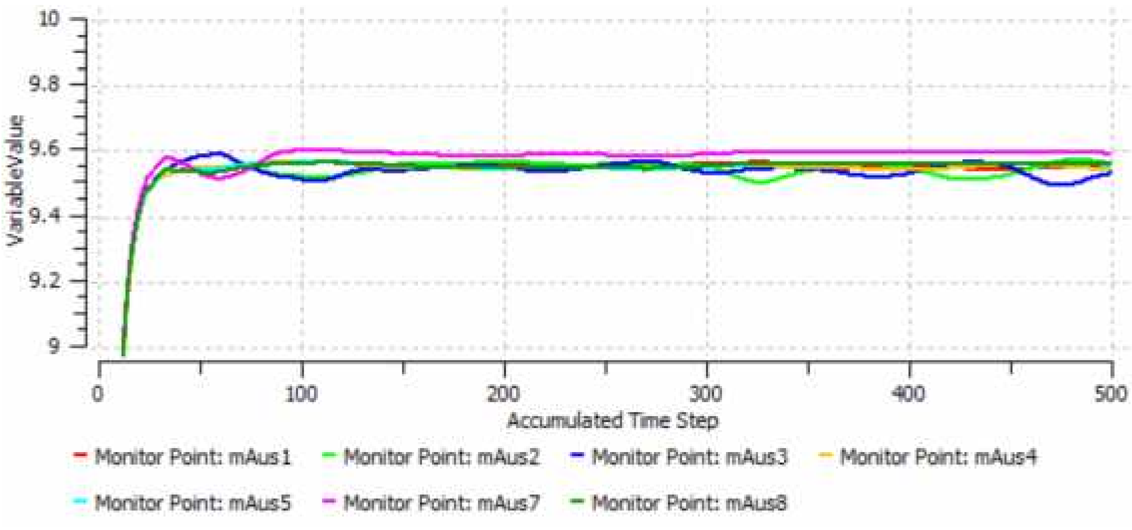

Figure (4-11) Calculated mass flow distribution [kg / s] in the seven outlet cross-sections during the iterative solution for the initial geometry and without partition, burner 6 switched off

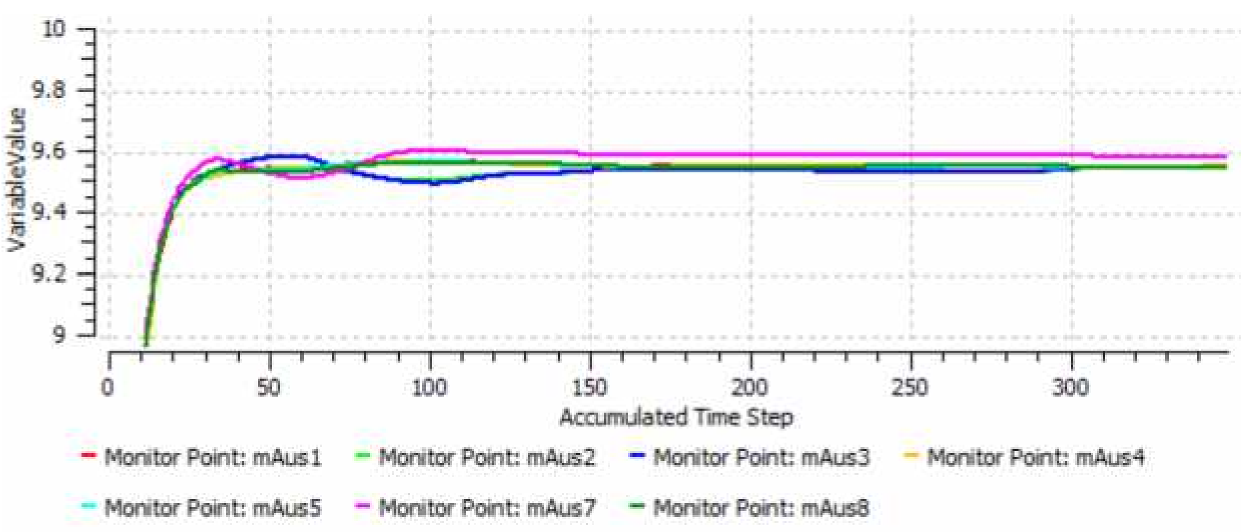

Figure (4-12) Calculated mass flow distribution [kg / s] in the seven outlet cross-sections during the iterative solution for the initial geometry with lower partition, burner 6 switched off

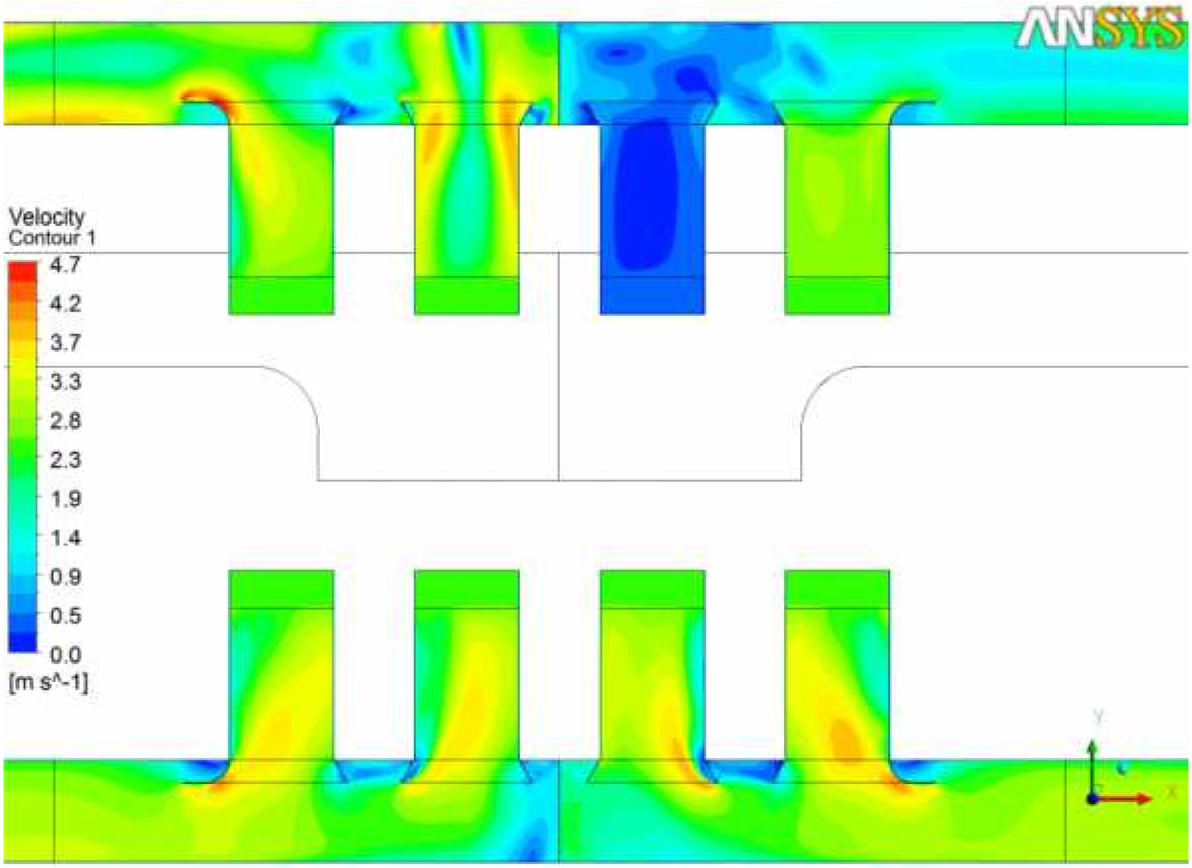

Figure (4-13) Calculated flow speed distribution in center plane of burner inlets, with upper and lower partition, load case 7 (7-burner 28% power (13 MW / burner), burner 6 switched off

4.6 Modified burner´s air flow inside housing and burner outlet

Subject matter of the investigations was the flow of the modified burner. At the inlet cross section, both a constant speed distribution is set, as well as in the study of the air supply calculated velocity profiles at the inlet cross section of the burner No. 5 each unfavourable distribution.

The calculations were based on the designed burner geometry including inlet air flap in opened position. Four different cases have been simulated:

Case 1: homogeneous inlet air speed distribution,

Qm = 8.4 kg/s, TE = 235 °C, pA = 2610 Pa, pU = 1 bar

Case 2: air speed profile of burner inlet No. 5 from original air duct geometry,

Qm = 7,84 kg/s, TE = 235 °C, pA = 2610 Pa, pU = 1 bar

Case 3: air speed profile of burner inlet No. 5, load case 110 %

Qm = 9,8 kg/s, TE = 165 °C, pA = 630 Pa, pU = 1 bar

Case 4: air speed profile of burner inlet No. 5, load case 3,

Qm 2,06 kg/s, TE = 130 °C, pA = 160 Pa, pU = 1 bar

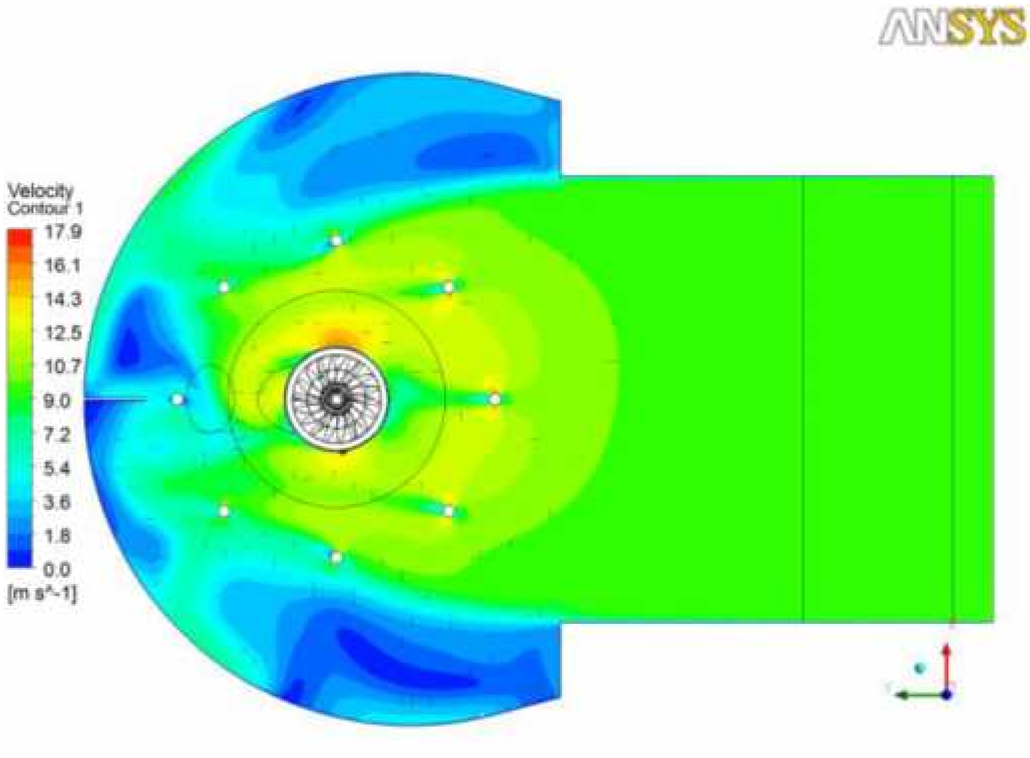

Figure (4-14): case 1, speed distribution x - y plain

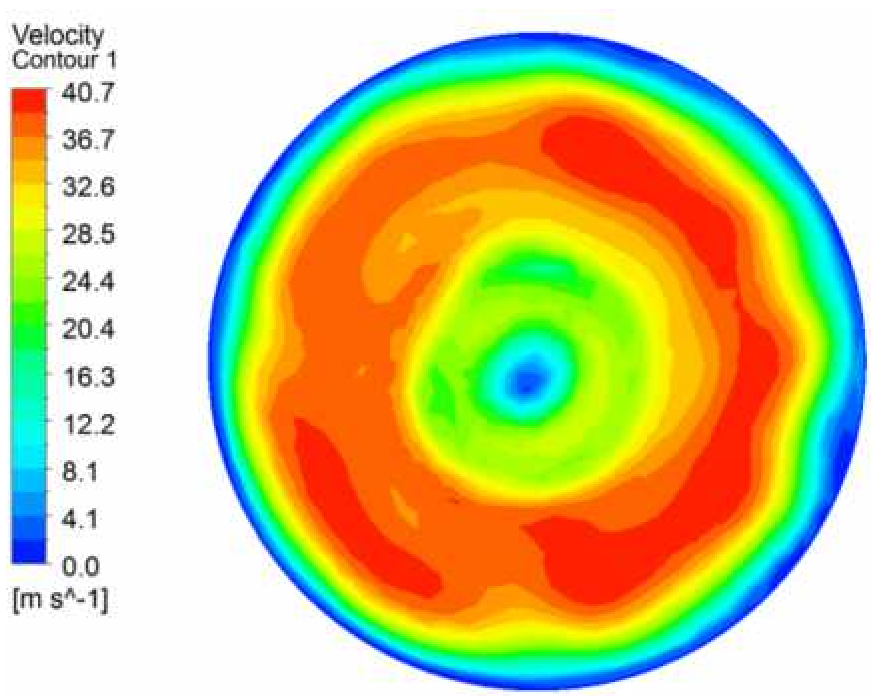

Figure (4-15): case 1, speed distribution burner outlet

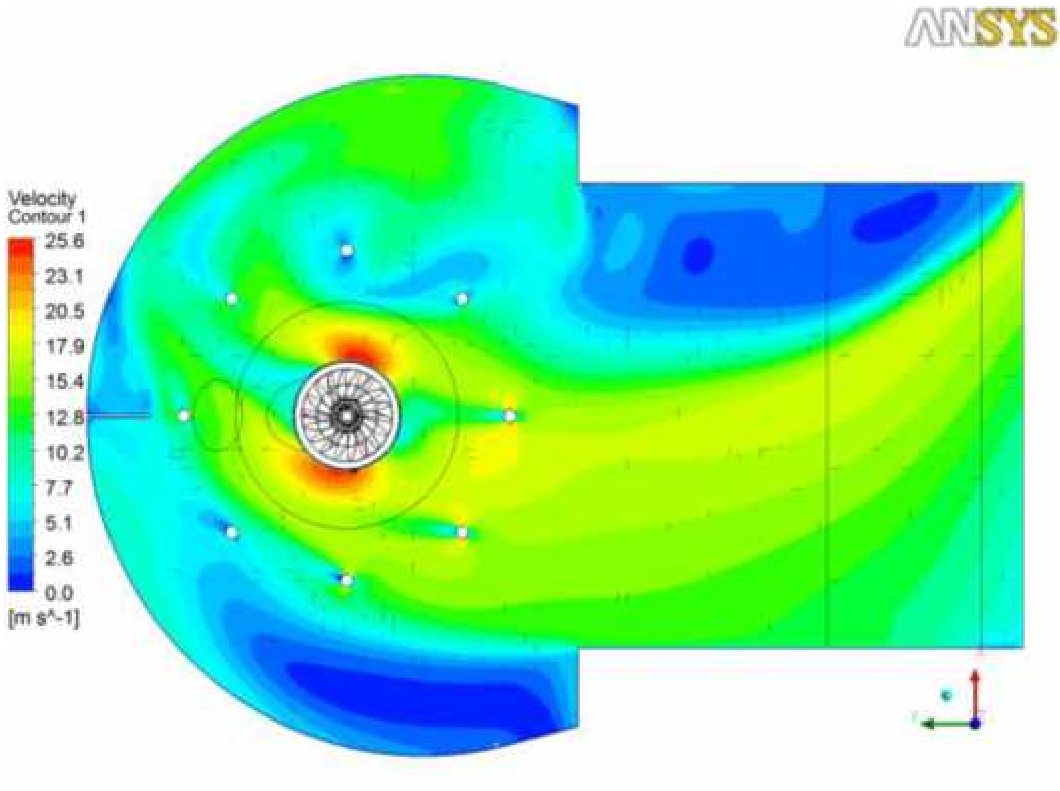

Figure (4-16): case 2, speed distribution x – y

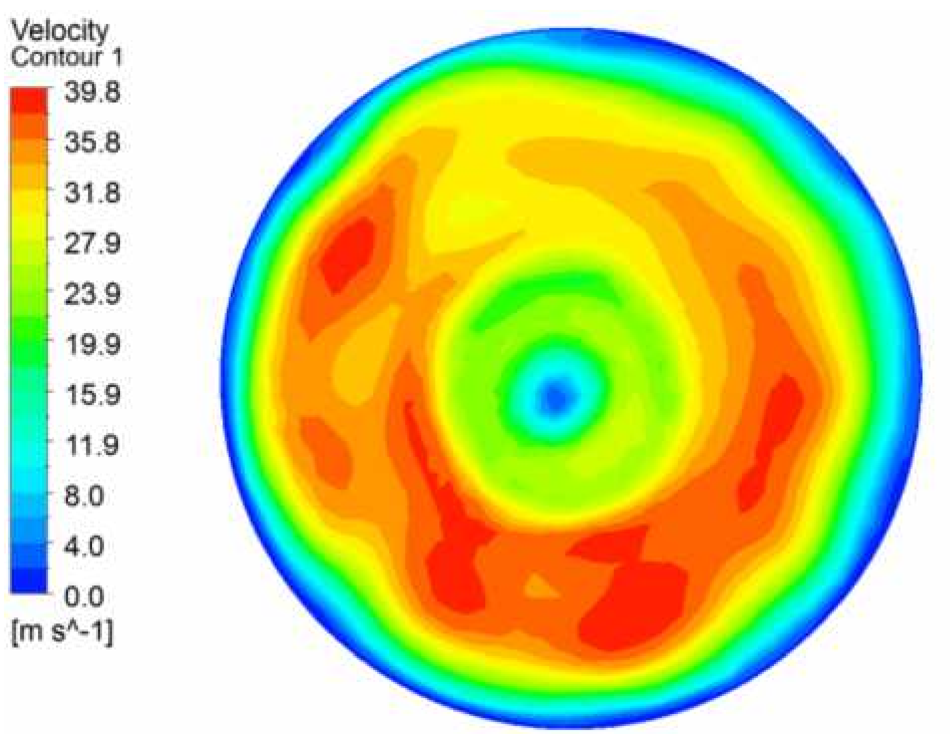

Figure (4-17): case 2, speed distribution burner outlet

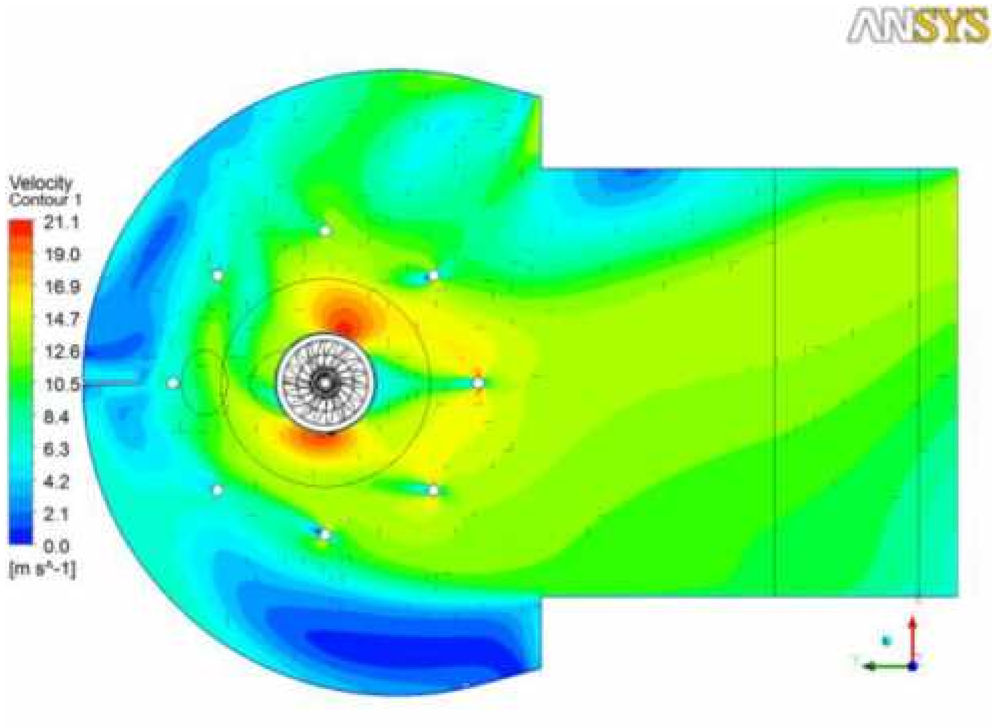

Figure (4-18): case 3, speed distribution x - y plain

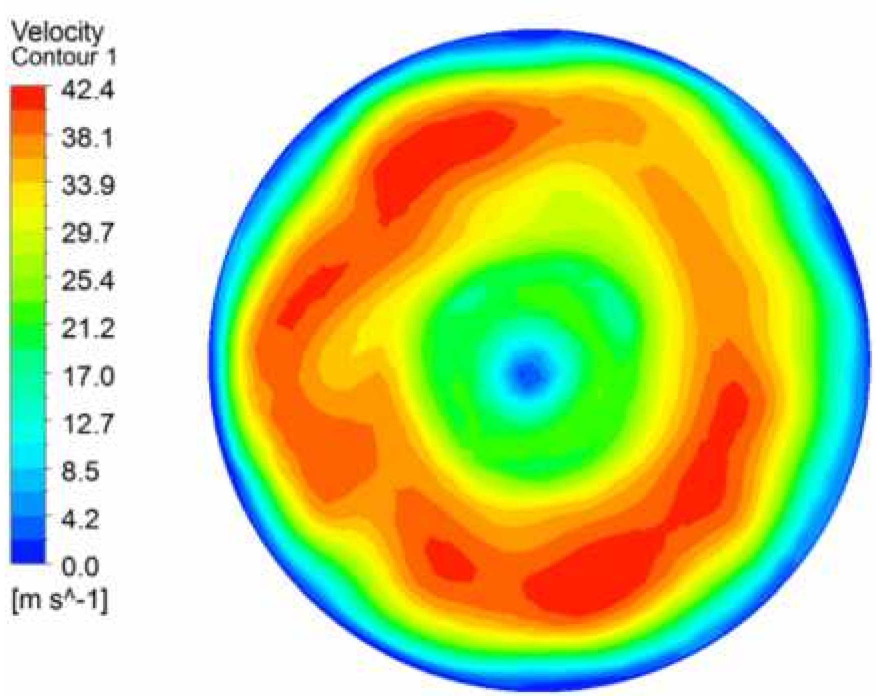

Figure (4-19): case 3, speed distribution burner outlet

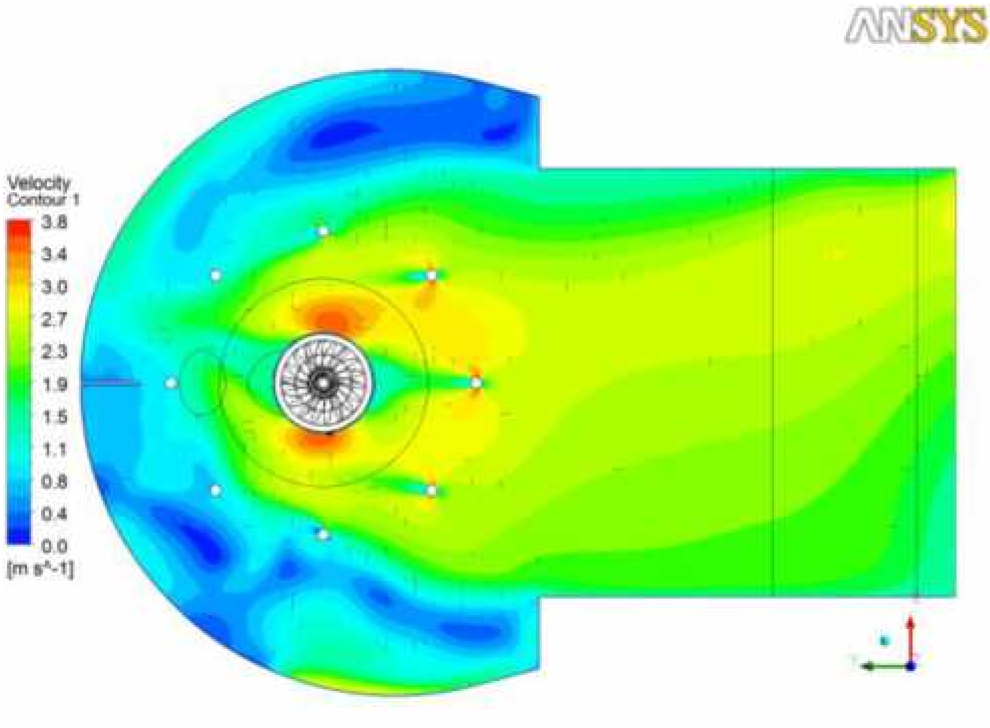

Figure (4-20): case 4, speed distribution x - y plain

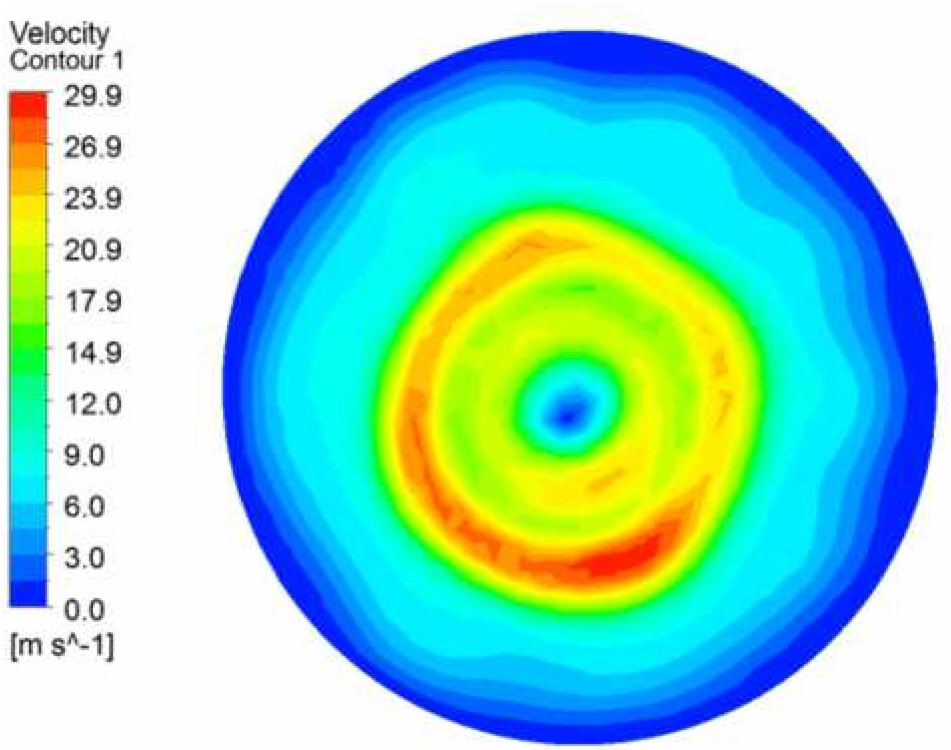

Figure (4-21): case 4, speed distribution burner outlet

As to be seen from the figures (4-14), (4-15) …. (4-21), the air flow distribution is homogeneous at the outlet, even if the air flow pattern at the inlet is not perfect.

Subject matter of the investigations was the flow of the modified burner. At the inlet cross section, both a constant speed distribution is set, as well as in the study of the air supply calculated velocity profiles at the inlet cross section of the burner No. 5 each unfavourable distribution.

The calculations were based on the designed burner geometry including inlet air flap in opened position. Four different cases have been simulated:

4.7 Implementation of the partition

KNPS implement the study of Phase 3 boiler 5 therefore it is very easy and low cost, the partition for air duct at the inlet to the burners by sheet metal, this partition leading to divided air from into two portion upper and lower part before wind-box of the burners.

So the noise level values in selected locations at KNPS after implementation of the partition of unit 3 and when other units is under no operation as mention below and the vibration of the boiler become at the normal operation so the unit increase the load up to design load without any restriction in operation by high noise or up normal vibration occur due to the boiler work with maximum load.

Location	noise level (dBA)
Administration room (1)	64
Administration room (2)	52.5
Administration room (3)	55
Administration room (4)	47
Electrical work shop	68
Water treatment plant control building	50
Turbine work shop	69
Control house	49
Instruments work shop	56
External maintenance	51.5
Chemistry laboratory	54
Boiler work shop	70

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

1. Conclusion

From this study we conclude that for Phase 3 boiler no. 5 with partition of the left and right part of the upper and lower headers and with the air guiding vanes and contours at the entrance to the burners, the bad air speed distribution at the burners can be eliminated. Fluctuations of the air flow different between the upper and lower burners will disappear. The modifications at the burners are excellent from aerodynamically point of view.

2. Recommendation

For phase 2 boiler no. 3 the partition proposed to the wind-box will equalize the amount of air flow to the three stages of burners and eliminate the source of noise and vibration occur due to induce flow (IF) of air and gas, also the shape of flame will be approximately the same in all the burners.

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APPENDIX

Appendicess 1

Internationa Journal of Engineering Sciences Paradigams and Researches

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Noise and Vibration in Boilers on High Loads

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Abstract

The basic purpose of the boilers is to convert the chemical energy in fuel into thermal energy that can be used to generate steam or hot water. Inside the combustion chamber, two fundamental processes must occur to achieve this objective. First, the fuel must be mixed with sufficient oxygen to allow sustained combustion and second the heated gases produced by the combustion process must then transfer the thermal energy to a fluid such as water or steam. Various components inside the boiler are required to promote efficient combustion and heat transfer. Their design depends on factors such as the type of fuel and the method selected to transfer thermal. The maximum power output from any thermal power plant is top priority for engineers, and maximum power output means maximum loads which related to maximum fuel consumption and air flow control system (A/F ratio). Vibration and noises resulted from the over dose of air –fuel ratio in boilers is the main consideration of this research project. The demand for electricity in peak-loads generates an unacceptable noise and vibration. This research tries to find a solution for these two problems in Khartoum North Power Station (KNPS) as case study. Physical measurement of the vibrations in the boilers by measuring probes is difficult in the running boiler due to high temperature. So, there is a need to evaluate vibrations in affected regions theoretically. Computational Fluid Dynamics (CFD) tools have been found appropriate to perform the flow analysis. Owing to recent improvements in CFD, simulation and flow analysis for the gas is now practicable for industrial purposes.

Keywords: *Boilers, Noise, Vibrations, Computational Fluid Dynamics, Draught.*

1. Introduction

Water tube boilers are constructed of various types of steel panels made of tubes that have pressurized water flowing through them. The combustion fluctuation pressure occurs inside boiler furnace could be critical factor which generate noise and vibration. Flow induced vibration for boilers subjected to cross-flow have been a subject of investigation all over the world. In boilers, this flow cause internal forces which may generate vibrations and noise in the boiler during their regular operation. These vibrations can lead to tube thinning at support points and consequent leakage or damage to tubes and wear, damage to structural attachments as well as insulation cladding provided around the boiler. It could lead to forced shutdown of boiler to replace the damaged components or lost the boiler. Excessive noise can be a problem to plant operating personnel. Vibration and noise problems are occur when air or flue gases flow over the boiler[1].

Crucial problems of up normal noise and high vibration appeared during boiler operation on high loads of power station they are start gradually at high load and increase till they got unacceptable at full load and finally leads to shut down the boiler.

The vibrations of tube bundles / casing / panels are due to a scientific phenomenon known as flow induced (FI).

In heat exchangers, such as boilers for commercial use, acoustic resonant noise is occasionally generated in the ducts when gas is flowing laterally with respect to the axis of the tubes. The acoustic resonant noise generated from heat exchangers is usually caused by the resonance of acoustic modes inside the boiler and vortex shedding from the tube banks[2].

In boilers and ducts systems the source of noise can be from fans, improper ducts design, and abrupt transitions, the natural flame instability in any flare or furnace produces noise. In rare cases, though, it is loud enough to draw complaints from the neighbors and even vibrate equipment to destruction.

Noise formed by a flame only (due to burner instability). This type of noise usually is not very loud, but it increases as the pressure and flow of fuel and air increase.

2. Methodology of the Research

2.1 Case Study

The Dissertation will take Khartoum North Power station (KNPS) as case study, it is a thermal power plant, built in three phases with total capacity of 380 MW and 6 units [1].

Phase 1, was built in 1984 including unit 1 and unit 2, capacity of each unit is 30 MW.

Phase 2، was built in 1994 including unit 3 and unit 4, capacity of each unit is 60 MW.

Phase 3، was built in 2011 including unit 5 and unit 6, capacity of each unit is 100 MW.

The traditional original burners “high NOx” in phase 2 was installed on the boiler in 1994 , where these burners were replaced in 2008 by low NOx burners to keep boiler emission from the chimney within international standard range of NOx standard to protect the environment from pollution as Environment Protection Authority (EPA). The new burners is so different from the original manly the arrangement of primary and secondary air flow, oil burners and nozzles.

Therefore, after this modification all parameters of combustion emission are within the international standard, but there is a crucial problems appeared during boiler operation on high loads it got up normal noise and high vibration start gradually when the engine load exceed 40MW and increase till they got unacceptable so the unit can’t reach the maximum load at all. Continuous noise is normally defined as broadband noise of approximately constant level and spectrum to which the employee is exposed to for a period of 8 hours per day, 40 hours per week. A large number of industrial operations fit into this class of noise exposure. The Occupational Safety & Health Administration (OSHA) noise standard [3], 29 Code of Federal Regulations (CFR) 1990-95 (a) and (b) defines the Permissible Exposure Level (PEL) as that noise dose that would result from a continuous 8 hour exposure to a sound level of 90 dB [4].

2.2 The Objective

From this study, accepted design modifications for burners and air supply ducts will be essential to increase the load of units till full load of 60 MW is possible and adjusting of operation parameters have been developed to operate boilers on the normal vibration and noise level to keep Khartoum North Power Station phase 2 operating on acceptable load according to designed capacity.

3. Computational Fluid Dynamics (CFD)

The combustion process inside a modern water tube boiler is a complex phenomenon, consisting of numerous chemical reactions all of which play an important role in boiler performance. Traditionally these boilers were designed using lumped thermal models of the combustion reactions to determine fluid composition and properties. However, these methods required

empirical correlation factors that may not have been appropriate for all applications.
Physics in the CFD model include: tracking of the fuel particles, evaporation and depolarization of these particles, surface combustion on the fuel particles, the combustion process in the gas, radiation heat transfer and pollution formation.
A high level of geometric detail is included in the model to capture certain key results. The geometries considered in detail are the fuel spreaders, the combustion air system and furnace. The tube banks of the various heat exchanger sections are also included.

4. Governing Equations

The conservation equations for mass, momentum and energy in general form are shown below.

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{V}) = 0$$

$$\frac{\partial}{\partial t}(\rho\vec{V}) + \nabla.(\rho \vec{V}\vec{V}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla.(\vec{V}(\rho E + p)) = \nabla.\left(k_{eff}\nabla T - \sum_j h_j J_j + (\bar{\bar{\tau}}_{eff}.\vec{V})\right) + S_h$$

$\bar{\bar{\tau}}$, the stress tensor is given by

$$\bar{\bar{\tau}} = \mu\left[\nabla\vec{V} + \nabla\vec{V}^T - \frac{2}{3}\nabla.\vec{V}.I\right]$$

Where I is the unit tensor.

The CFD program solves the Navier–Stokes equations with different kε-models or an implemented kω-model for the unsteady turbulent viscous and incompressible flow field [5]. The object of this project is to find a model, which describes the gas flow vibration excitation and enables an accurate computation of critical velocities in ducts, burners and furnace of the boiler

5. Draught (see also Furnace Draught under Fans)

Draught is defined as current of air/gas, especially the one intruding into an enclosed space. In boiler draught signifies the pressure difference below that of the atmosphere. Flow of air and gas inside boiler is also generally termed as boiler draught[6].
Early boilers operated under induced/natural draught, which relied entirely on the stack without the aid of fans, to provide air and gas flow through the boiler, purely by the ρ difference of air between the bottom and top of the stack.
Modern boilers with so many tube banks inside and HP SA/TA can scarcely operate on the meagre stack effect and need fans for creating adequate draught.
Balanced and FD are the two modes of boiler operation depending on whether the gas pressure in furnace is neutral (furnace static pressure = atmospheric pressure) or positive. Both types of operations are depicted in figure (1) below which shows the profile of air and gas pressures across a typical boiler.

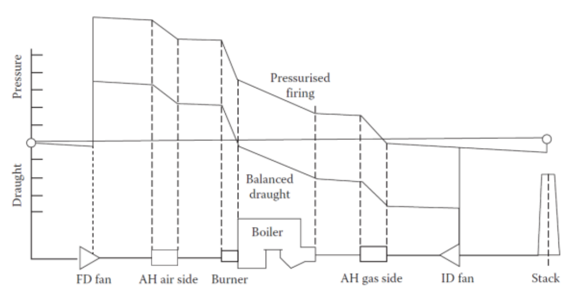

Figure 1: Draught profiles in forced and balanced draught firing

Target of the investigation was the complete air supply system of boiler 3 in Khartoum North Power station. The air supply system overview can be seen from picture 2. The whole geometry was assembled from sub geometry parts. Main goal was to find solution for bad air distribution to the burners in certain load cases.

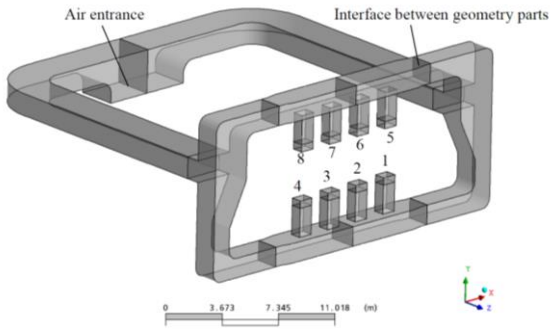

Figure 2: To be calculated duct geometry with designation of the eight burner inlets

6. Geometry & boundary conditions

The calculated flow field extends from the outlet of the air preheater to the burner´s wind boxes (without flaps). The pressure drop of the burner is represented by a respective porosity. Since the porosity affect the velocity profile, a channel length of L= 2000 mm was chosen for the burner outlets for clarity / sensing the flow conditions at the burner inlet.

The air mass flow rate is Q_m = 66.9 kg/s. Velocity profile was chosen as a constant distribution in the inlet cross-section. The resistance coefficient of porosity was determined by the conditions:

$Q_{m,B}$ = 66.9 / 8 = 8.3625 kg/s
Δ_{pB} = 21 mbar
p_{FR} = 25 mbar(ü)
p_U = 1 bar
T_L = 235 °C.

The static pressure in the outlet section is pA = 2500 Pa (pressure in the combustion chamber). As turbulence model, the k-□-Model was used. The walls were defined as rough with k = 0.3 mm. Generally apply to the calculations the following conditions:

Fluid:
Air (compressible, assumed as an ideal Gas)

Properties Air:
η = 2.609 · 10-5 N·s/m2
λ = 2.61 · 10-2 W/(m·K)
c_p = 1026 J/(kg·K)
M = 28.96 kg/kmol

Boundary conditions:
Q_m = 66.9 kg/s
T_E = 235 °C
p_A = 2500 Pa(ü)
p_U = 1 bar(a)
Δ_{pP} = 2100 Pa

Wall-rest conditions: adiabatic:
coarse with k = 0.3 mm

Turbulence model:
k-ε - Model with T_{uE} = 5 %

7. Results and Discussion

7.1 Flow condition of the existing supply system

Figure 3 show the simulated streamlines in the air duct. Striking is a largely parallel flow in the lower plenum and a vortex / swirl in the upper plenum, caused by flow of the air into the manifold (tees). Because expansion factor Inflow / Distribution surface is 2:27, the air flow breaks away. The constriction in the direction of lower distribution channel ensures stable flow condition. The constriction in the direction of the upper manifold duct, in conjunction with the deflection leads to the formation of swirl inside the flow pattern

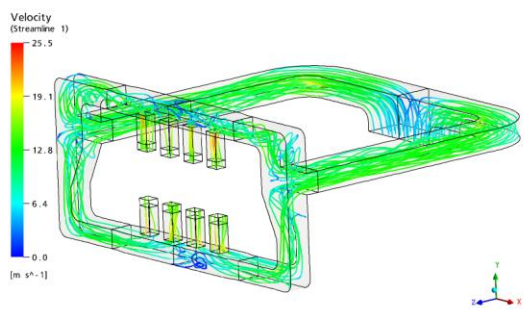

Figure 3: Calculated Stream lines

The calculated mass flow deviation between the individual burner outlets is relatively small. The air supply is symmetrical, so that a symmetrical distribution is expected. The calculated mass flow rate of each burner is also equal to two symmetrical. In the lower branch, however, represents a periodic mass flow fluctuation in the burner outlets. This clearly shows the calculation without porosity.

7.2 Flow conditions in the tee

As before mentioned, the air flow breaks away inside the tee. Reason is the larger cross-section inside the tee compared to the duct between the air preheater and the tee.
It has been carried out several calculations, how the flow pattern can be upgraded. But there was no solution without judge modification at air channel´s side walls. The remaining swirl inside the upper header is not disturbing the entrance of the air towards the burner inlets too much. So it was decided, to use the tee as it is and avoid extended modifications in this area.

7.3 Flow Conditions at Burner Inlets

The sharp deflection at the burner inlet of the original geometry causes a velocity distribution in the flow towards the burners. In this section, the geometry for the improvement was examined. Best result is shown in Figure 4 Version 3: inlet funnel 30 °, R = 300 mm upstream + guiding vane L = 300 mm, height 300 mm.

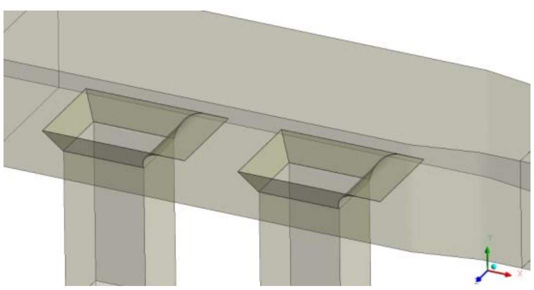

Figure 4: Geometry Version 3

Calculated velocity distributions show Figure 5 and Figure 6.

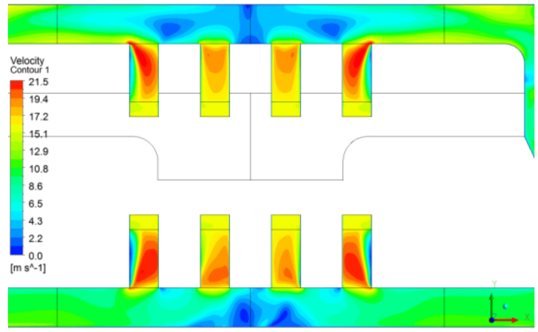

Figure 5: Calculated velocity distribution in the center plane in burner´s inlets (original geometry)

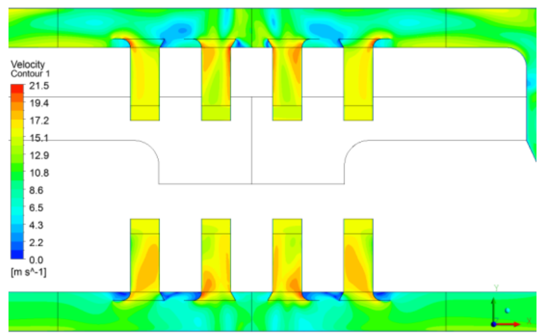

Figure 6: Calculated velocity distribution in the center plane in burner´s inlets (geometry option)

7.4 Modified burner´s air flow inside housing and burner outlet

Subject matter of the investigations was the flow of the modified burner. At the inlet cross section, both a constant speed distribution is set, as well as in the study of the air supply calculated velocity profiles at the inlet cross section of the burner No. 5 each unfavourable distribution.
The calculations were based on the designed burner geometry including inlet air flap in opened position. Four different cases have been simulated:
Case 1: homogeneous inlet air speed distribution, Qm = 8.4 kg/s, TE = 235 °C, pA = 2610 Pa, pU = 1 bar
Case 2: air speed profile of burner inlet No. 5 from original air duct geometry,

Qm = 7,84 kg/s, TE = 235 °C, pA = 2610 Pa, pU = 1 bar

Case 3: air speed profile of burner inlet No. 5, load case 110 %

Qm = 9,8 kg/s, TE = 165 °C, pA = 630 Pa, pU = 1 bar

Case 4: air speed profile of burner inlet No. 5, load case 3, Qm 2,06 kg/s, TE = 130 °C, pA = 160 Pa, pU = 1 bar

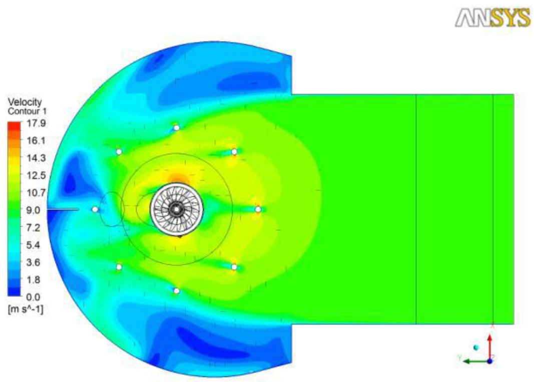

Figure 7: case 1, speed distribution x - y plain

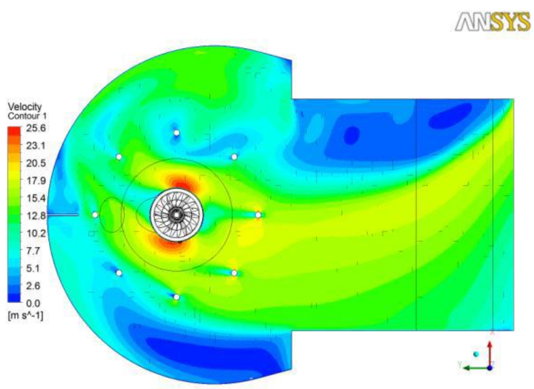

Figure 8: case 2, speed distribution x - y

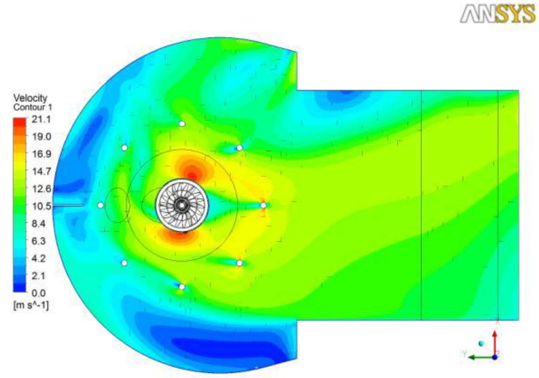

Figure 9: case 3, speed distribution x - y plain

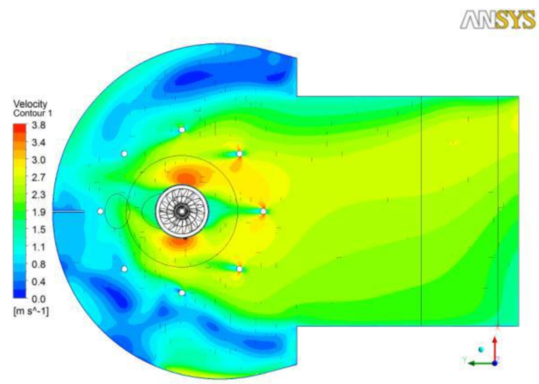

Figure 10: case 4, speed distribution x - y plain

As to be seen from the figures 7 … 10, the air flow distribution is homogeneous at the outlet, even if the air flow pattern at the inlet is not perfect.

8. Conclusion & recommendation

With partition of the left and right part of the upper and lower headers and with the air guiding vanes and contours at the entrance to the burners, the bad air speed distribution at the burners can be eliminated. Fluctuations as before (in case of lower load at the burners) will disappear. The modifications at the burners are excellent from aerodynamically point of view and solve the main source of noise and vibration and the boiler will run very stable with high efficiency, performance and at acceptance level of environmental aspect.

Acknowledgments

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