1. Abstract

Previously, an old existing industrial burner are producing and emitting high amount of NO_x emissions. Precessing Jet (PJ) nozzle is a new technology burner that alter the way of mixing fuel and air to a whole new means. It is proving to combine economic and environmental benefits in a wide range of industrial combustion processes. Compared with conventional combustion technologies, the PJ nozzle has the ability to reduce pollution (NO_x emissions) significantly while simultaneously increasing radiant heat transfer. The PJ burner is associated with commercial and as well as environmental benefits. However, PJ nozzle is only capable of using gas as it main fuel. Despite these acknowledge benefits, many plants (especially in USA) are not choosing to adopt this technology because of their requirement to be able to fire oil when natural gas is not available, notably during the winter months when the demand for natural gas is high. To date a dual-fuel combustion system, to allow firing natural gas or oil, has not been developed

2. Projects Aim & Requirement

The aim of the project is to investigate and examined the characteristics of the aerodynamics profile flow of the combined system, using cold flow physical model.
The study of this project will give a benchmark in the design of dual-fuel PJ nozzle to address the above limitation which is to be able to fire oil when natural gas is not available. The conclusion of the data will be the starting point for more intense study of the dual-fuel jet nozzle development.
As mentioned, the project is mainly about undergoing experimental study on aerodynamics of combined fuel system. Therefore, to achieve the aim stated above, there are several specifications and requirements required:

a) Model of oil nozzle/spray
A model of oil nozzle based on the typical industrial prototype is to be design and prepared. The critical issues of the design need to be noted are 10-20% of swirl air, axial air, droplet size and jet atomiser.

b) Flow visualisation
To visualised the effect of off-centred nozzle on the asymmetric of the oil spray nozzle

3. Literature review

The project literature review includes the skim and detail reading of various books and article regarding gas and liquid fuel burner/nozzle. Listed below are the main article and books and its summarise :

A) Title: The precessing jet gas burner-a low NO_x burner providing process efficiency and product quality improvements.
Author: C.G Manias and Dr G.J Nathan
Summarise:

- The detail of gas burner equipment

- History and the mechanism of PJ nozzle
- Product quality improvement by using PJ nozzle
- Mechanism of reducing NO_x emission and increased radiant heat transfer

B) Title: An axisymmetric 'fluidic' nozzle to generate jet precession
Author: G.J Nathan, S.J Hill and S.E Luxton
Summarise:

- The important of asymmetric flow in generating jet precession
- The study of precessing frequency in the function of Strouhal Number (dimensionless parameter)
- Experiment detail and investigation of precessing jet and axial jet flow

C) Title: Combustion Aerodynamics
Author: J.M Beer and N.A Chigier
Summarise:

- The detail of swirling flow and swirl generation
- The effect of the degree of swirl
- Oil burner, droplets and sprays

D) Title: Combustion of liquid sprays
Author: A. Williams
Summarise:

- Mainly the detail of liquid fuel burner
- Properties of sprays and experimentation method
- Atomisation of liquid fuels
- Pollutants control from spray combustion

The literature research however, is lacking information especially in the area of dimensional analysis. Most of the information gathered was from the interaction and discussion with the supervisors.

4. Theoretical Work

4.1 Dimensional Analysis

Dimensional analysis is a method of modeling the practice of predicting the performance of a full-scale plant by interpreting the results of a model experiments. The similarity between the process investigated in the model and in the prototype is required for a result from the experiment to be projected as the prototype. In this project the similarity required are the geometrical and also the mechanical (kinematic & dynamic).

An industrial PJ burner used in a typical cement industry has the capacity of 60-65 MW. For the experimental purposes the capacity is scaled down to a lower capacity for a simplification and also economical reason. A scaling of 10MW, 3.31 MW, 1MW and 0.5 MW is chosen.

Below are the simplified table of the dimensional analysis.

Capacity	60 MW		10 MW		3.31 MW		1 MW		0.5 MW	
Properties	PJ (N.G)	Oil	PJ (N.G)	Oil	PJ (N.G)	Oil	PJ (N.G)	Oil	PJ (NG)	Oil
	m^3/s	kg/s	m^3/s	kg/s	m^3/s	kg/s	m^3/s	kg/s	m^3/s	kg/s
Volume or Mass Flow Rate	1.6172	1.47058	0.2695	0.24516	0.0891	0.08103	0.0269	0.02451	0.0134	0.01225
Stoichiometric Air, m^3/s		15.7985		2.63309		0.87031		0.26330		0.13165
Air Flow Rate (15% of primary air), m^3/s		2.36978		0.39496		0.13054		0.03949		0.01974

Table 1: Properties of the system with various capacities

After further consideration, a decision is made that a scaled model of 3.31 MW is going to be used in the experiment. The main factor that influenced the decision is that the fact that there exist a PJ nozzle of 47 mm diameter.

4.2 Stokes Number

Critical dimensionless groups in this project are Reynolds Number and also Stokes Number. Both of this dimensionless group projects the flowability or transportability of the fluid. However, it is impossible to achieve a constant Reynolds and Stokes Number or any two dimensionless group simultaneously. A constant Reynolds Number will sabotage Stokes Number and vice versa. A superior or more important dimensionless group is to be chosen and hence after thorough investigation and discussions with Dr. Gus Nathan, Stokes number is chose. Stokes Number describe the time scale of an objects under the flow of a fluid. The Stokes Number from the prototype is to be maintained in the experiment.
Stokes Number is given by the formula below:

- Stokes Number, $S_t = \rho_p U d_p / 18\ \mu\ L$

where, ρ_p= Difference of Particle and Fluid density
U = Fluid velocity
d_p = Particle diameter
μ = Fluid viscosity
L= Pipe Orifice

Stokes Number of the prototype is calculate based on the 60MW PJ burner geometry with taking note that typical industrial droplet diameter of the liquid fuel for the liquid spray is 60 micronsmetre.

St (full scale) = rho*U*d / 18 *mu* L
= (950-1)* 51.47 *(60*10^-6)*/(18*0.00017*0.2)
= 4788.728431

St (model) = rho*U*d / 18 mu L
= U*d*[(1000-1)*(1*10^-6)/(18*0.00017*0.047)]
= 6.946*U*d

St(full scale)	=	St(model)
4788.728431	=	6.946*U*d
U*d	=	689.4043273

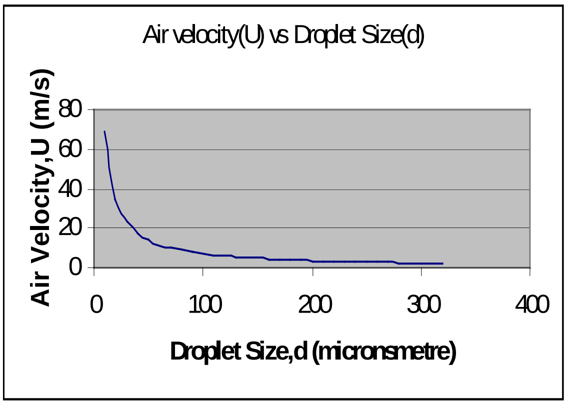

Fig.1: Relationship between U and d

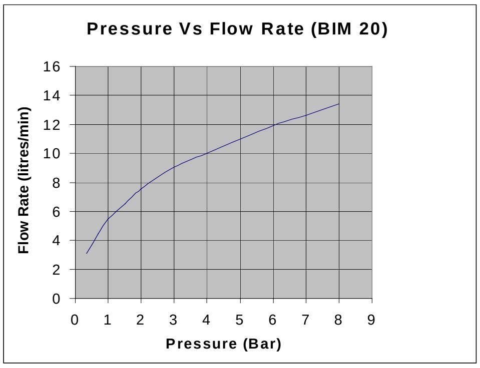

Fig.2: Pressure and flow rate distribution of spray nozzle.

Air velocity, U is a variable that can be controlled manually to maintained a constant Stokes Number. The value of air velocity is depends on the droplet size produced by the spray nozzle. In general however, spray nozzles do not generate droplets of equal size. Liquid break-up is caused by the collapse of unstable fluid sheets, jets or ligaments, or by the shearing action of air. These mechanisms produce a broad spectrum of droplet sizes; often submicron up to several hundred microns in the same spray. Hence, 'd' is the diameter of the mean average droplet size produced by the nozzle. In addition to that, the quality of atomisation is very much influenced by the operating condition and also the properties of the fluid. For a given flow rate, a higher operating pressure or temperature of the fluid will results to a fine atomisation meanings a small droplet size. On the other hand, an increase in fluid viscosity and surface tension will produced coarse droplet size. With this understanding, and also lack of information from the spray nozzle manufacturer about the droplet size, an experiment to obtained the droplet size is essential in this project in order to used the right air velocity and then maintained a constant Stokes Number.

5. Experiment

The precessing jet (PJ) nozzle is mechanically simple and has no moving parts. The jet which emerges from the nozzle is in a state of perpetual oscillation, or precession. The precession motion is generated by a naturally occurring flow phenomenon within the nozzle chamber. This phenomenon is not allowing liquid nozzle to be placed in the centre of it nozzle chamber as other conventional gas burner do. An alternative placement of liquid nozzle is required. One of the alternatives that is going to be implemented in this project which is to placed both nozzle alongside (parallel) each other. However, by doing this, the liquid nozzle will be off centred and the effects of its is to be investigated. An aim of this project is try to maintained or corrects the asymmetry of the flow when the nozzle is off centred.
With this understanding, the present of the PJ burner is unnecessary in the experiment. The experiment only consists of liquid nozzle, which also accompanied by swirl air and annular air as primary air. The theoretical primary air is about 10%-20% of stoichiometric air. The experiment will however used primary air of 15%

stoichiometric air.
Figure 3 (on page 7) are the simplified layout of the experiment:

The experiment consist of 3 line flexible pipe hose. Each hose are for the water supply, annular air and swirl air respectively. The flow rate of the water and air supply is controlled manually using valve connected to each supply line. The water flow rate is about 5.12 litre/min or 4.86 kg/s. According to the spray nozzle manufacturer, it required a driving pressure of about 0.85 bar (refer to figure 2). The total air flow rate (annular +swirl) is about 0.13 m^3/s. The velocity of the air flow is measured using manometer tube. Both manometer tubes are indicated by point A and B on the experimental layout. The velocity are calculated using formula

$P=1/2 \times \rho \times V^2$

where P= dynamic pressure
ρ= air density
V= velocity

Figure 4 (page 7) below shows the detail overview of the nozzle.

The experiment has two parts:

1) <u>Droplet Size Measurements</u>
As mentioned earlier, droplet size measurement is essential in order to maintained a constant Stokes Number. The experiment is undergone using liquid nozzle and water without any flow of air (under suggested operating condition). A laser sheet of light is passed trough the spray. Camera is then used to capture the water droplet. Then a careful and systematic measurement of the film take placed by roughly measuring the droplet size.

2) <u>Asymmetric Experiment</u>
The aim of this experiment is to investigate the effect of off-centred nozzle on the flow asymmetric. It also includes the experiment to correct the asymmetry of the flow by making some changing on the annular air flow. The liquid nozzle is made up to be able to move radially from the centre. This is done using 'O-ring' that is attached between the annular air channel and the swirl air channel. The degree of movement of the liquid nozzle can be adjusted easily using the screw attached. The outlet of the annular air channel is covered with a thin perforated plate. This perforated plate is easily assembled or disassembled from the nozzle. The shape of holes on the perforated plate is to be designed or drilled so that the flow asymmetric of the off-centred nozzle is corrected or at least improved. There will be a couple of different design plate to be used in the experiment. However, the area of the annular air must be equal with area of the swirl air in order to give the right momentum. The laser sheet and camera is used for the flow visualisation.

Future Work

The equipment or the nozzle is under build. The experiment will commence immediately after the nozzle is complete. The experiment is scheduled to be commencing on 20th September 01. It will be held at Holden Lab, University of Adelaide. The results and final report writing will be submitted on 24th October 01.

Conclusions

A theoretical and experimental approach of the project has been highlighted and presented. The paper describes the guideline and the strategy of achieving the objective of the project. Asymmetry of the flow is a great important in producing jet precession. The aerodynamic experiment and testing of the spray nozzle will be mainly concern of the asymmetric flow assessment and modification and configuration of the combined model to achieve the characteristic flow.

The outcome of the project will give a great benefit and impact on the combustion industry due to its commercial benefits and improvement in environmental emissions.

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9. REFERENCES

Beer, J.M. and Chigier, N.A. 1992 "Combustion Aerodynamics", Applied Science Publisher, Essex, England.

Manias, C.G. and Nathan, G.J. The precessing jet gas burner-a low NO_x burner providing process efficiency and product quality improvements, *International Kiln Association Conference*, Toronto, Canada, October 1992.

Nathan, G.J., Hill, S.J. and Luxton, S.E. 1998 An axisymmetric 'fluidic' nozzle to generate jet precession. *J. Fluid Mech*. **370**, 347-380.

Newbold, G.J.R. (1997) "The Fluid Mechanics and Combustion Characteristics of a Precessing Jet Flow", PhD Thesis, The Department of Mechanical Engineering, The University Of Adelaide.

Rayleigh (Lord) (1879). Proc. London Math. Soc., 10, 4-13.

Weber, C. (1931). Z. Angew Math. Mech. engrs., 18, 240

William A, 1990 "Combustion of liquid fuel sprays", Butterworth, London.